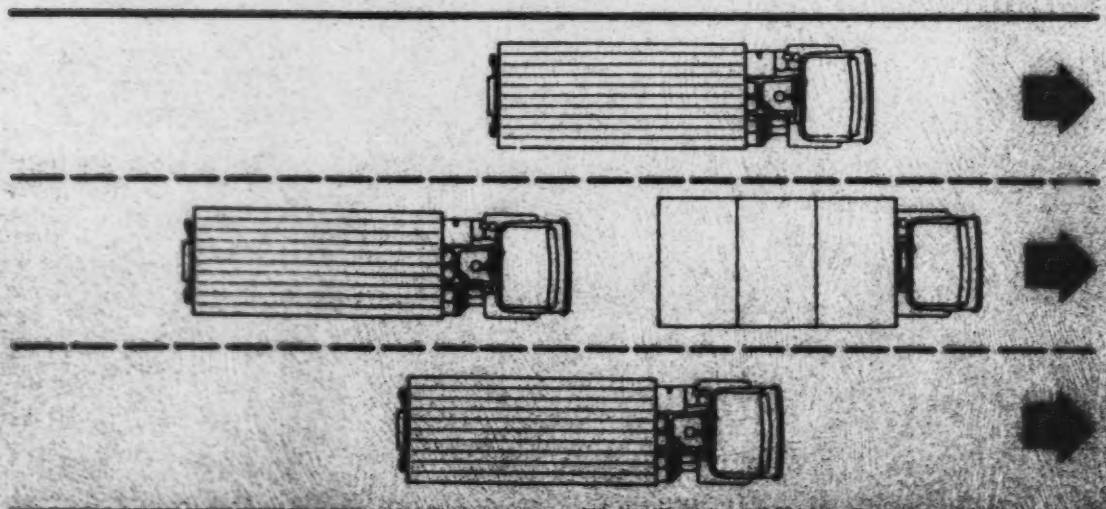
SRR-84-10

Multiple Presence Surveys of Commercial Vehicles In Ontario 1981 and 1982



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Abstract:

During five days in 1981, traffic was monitored on Hwy 69, a two-lane highway north of Parry Sound. Approximately 30 trucks/h, 20% of the traffic volume, used the highway and travelled between 50 and 90 km/h. For four days in 1982, traffic was monitored on southbound Keele Street at the Hwy 401 overpass. Approximately 75 trucks/h, 5% of the traffic volume, travelled on the three lanes. Traffic was frequently congested and occasionally stopped.

Vehicles were classified and speed and headway were recorded. On ten lane lengths truck presence was counted in single and multiple lane groups: i) for moving traffic and ii) for simulated congested traffic. Congestion was simulated by reducing space between vehicles to 2 m. Modified Poisson distributions (modified to account for truck length) were fitted to the data. The parameter of the distribution, effective mean truck headway distance, was calculated for each traffic lane. In moving traffic this parameter was, with one exception, smaller than the actual mean truck headway distance. For multiple lanes, the parameter was much smaller than the value calculated assuming independence of adjacent lanes of traffic. Thus, positive statistical dependence was apparent. For simulated congested traffic, this dependence was not apparent.

Key Words: multiple presence of trucks, traffic simulations, traffic surveys

Comments:

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Multiple Presence Surveys of Commercial Vehicles In Ontario 1981 and 1982

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TABLE OF CONTENTS

List of Figures iii

Acknowledgements v

1/ INTRODUCTION 1

2/ THE POISSON IDEALIZATION OF MULTIPLE PRESENCE 2

3/ COUNTING MULTIPLE PRESENCE 5

4/ TRUCK HEADWAY SURVEYS 7
4.1/ The 1981 Survey. 7
4.2/ The 1982 Survey. 7

5/ MULTIPLE TRUCK PRESENCE IN SINGLE LANES 8

6/ MULTIPLE TRUCK PRESENCE IN TWO AND THREE LANES 9

7/ CONCLUSIONS 11

REFERENCES 12

LIST OF FIGURES

1(a)/ Histogram of Headway Distance for Trucks Northbound on Highway 69 13

1(b)/ Histogram of Headway Distance for Trucks Southbound on Highway 69 14

2(a)/ Histogram of Headway Distance for Trucks in the Southbound East Lane of Keele Street. 15

2(b)/ Histogram of Headway Distance for Trucks in the Southbound Centre Lane of Keele Street 16

2(c)/ Histogram of Headway Distance for Trucks in the Southbound West Lane of Keele Street 17

3(a)/ Frequencies of Multiple Presence of Trucks Northbound on Highway 69 18

3(b)/ Frequencies of Multiple Presence of Trucks Southbound on Highway 69 19

4(a)/ Histograms of Multiple Truck Presence on Highway 69, Northbound 20

4(b)/ Histograms of Multiple Truck Presence on Highway 69, Southbound. 22

5(a)/ Frequencies of Multiple Presence of Trucks on Southbound Keele Street, West Lane. 24

5(b)/ Frequencies of Multiple Presence of Trucks on Southbound Keele Street, Centre Lane 25

5(c)/ Frequencies of Multiple Presence of Trucks on Southbound Keele Street, East Lane 26

6(a)/ Histograms of Multiple Truck Presence on
Keele Street, East Lane. 27

6(b)/ Histograms of Multiple Truck Presence on
Keele Street, Centre Lane 29

6(c)/ Histograms of Multiple Truck Presence on
Keele Street, West Lane. 31

7(a)/ Frequencies of Multiple Presence of Trucks on
Southbound Keele Street, Centre and West Lanes 33

7(b)/ Frequencies of Multiple Presence of Trucks on
Southbound Keele Street, East and Centre Lanes 34

7(c)/ Frequencies of Multiple Presence of Trucks on
Southbound Keele Street, East, Centre and West Lanes 35

8(a)/ Histograms of Multiple Truck Presence on Keele Street,
East and Centre Lanes. 36

8(b)/ Histograms of Multiple Truck Presence on
Keele Street, Centre and West Lanes. 38

8(c)/ Histograms of Multiple Truck Presence on
Keele Street, East, Centre and West Lanes. 40

9/ Mean Truck Headway Distances on Keele Street. 42

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1/ INTRODUCTION

Most bridges in the Ontario highway system were designed in accordance with the AASHTO (American Association of State Highway and Transportation Officials) Specification [1] which includes lane loads. Historically, the lane loads were first included in 1935 as rows of idealized trucks. In 1944, the HS series of uniformly distributed lane loads were specified with the following footnote:

> "These approximate the effects of the corresponding 1935 truck preceded and followed by a train of trucks weighing 3/4 as much as the basic truck".

Because truck weights increased and design methods changed, factors were specified in subsequent editions of the AASHTO Specifications which had the effect of uniformly increasing the magnitude of the lane loads. In this manner, multiple truck presence was considered in the highway live loads for bridge design during almost four decades.

Beginning in 1967, the Ontario Ministry of Transportation and Communications (MTC) began a series of truck surveys [2] and bridge tests. Based on these surveys and tests, decisions were made to increase the legal weight limits for Ontario highways and to prepare a new bridge design specification. When the Ontario Highway Bridge Design Code (OHBDC) [3] was being prepared, it was recognized that very little data was available on multiple truck presence, yet this random phenomenon has a major influence on the magnitude of some structural effects such as shears, moments, axial forces, and deflections. Thus, Phases I, II and III of A Study of Commercial Vehicles and their Multiple Presence [4, 5, 6] were carried out under the Ontario Joint Transportation and Communications Research Programme (Projects 23116 and 23141).

The objective of this publication is to summarize the headway and multiple presence data obtained during Phases II and III of the study. Observations of multiple truck presence are compared to the statistical distributions which result from an idealized random process.

2/ THE POISSON IDEALIZATION OF MULTIPLE PRESENCE

The arrival of vehicles versus time is frequently idealized as a Poisson process [7, p. 240]. In sparse traffic, this idealization is applicable because arrivals occur at separate, independent, random times and usually the mean arrival rate -- the number per day -- is approximately constant. By this idealization, the probabilities of 1, 2, 3, 4... vehicles arriving during an interval of time are calculated using the Poisson distribution.

Similarly, in sparse traffic it is reasonable to assume that the multiple presence of trucks is described by a Poisson distribution. Herein, the term "trucks" is understood to include all vehicles which are potentially heavy. The probability of no trucks present is omitted because the weights of light vehicles make only a minor contribution to bridge loading. Because many, if not most, influence surfaces for bridges have large influence coefficients over only a small area, one truck is almost always present in this area when a peak value occurs in the magnitude of the structural effect. Therefore, it is rational to calculate the probabilities of multiple truck presence conditional on one truck in a fixed location. Using the above assumptions, the probability of m trucks present on a highway segment of length ℓ conditional on one truck in a fixed location is:

$$p_m = \frac{1}{(m-1)!} \left(\frac{\ell}{\bar{x}}\right)^{m-1} \exp\left\{-\frac{\ell}{\bar{x}}\right\} \qquad (1)$$

where $\bar{x}$ is the mean headway distance between trucks. Also, in accordance with the Poisson assumption, the headway distance between trucks, distance x, has the following probability density:

$$f(x) = 1/\bar{x} \exp\{-x/\bar{x}\} \qquad (2)$$

In congested traffic, the Poisson idealization is questionable primarily for two reasons:

- Truck arrivals are not independent; vehicles move in groups.
- Each truck occupies an appreciable lane length; truck length relative to lane length ℓ is an important ratio which is not considered in a basic Poisson idealization.

There are millions of loading events during a bridge's lifetime. Therefore, an event with a very small probability of occurrence can be significant because it may have a significant expectation; that is, the product of the large total number of events and the very small probability of occurrence may be greater than unity. For this reason, it is important to use an idealization of multiple truck presence which gives an exactly zero probability to impossible events -- events with more trucks present than the number which would completely fill the specified highway length. Therefore, the basic Poisson distribution is modified as follows because it gives small but finite probabilities to large numbers of trucks in multiple presence events.

The mean length occupied by a truck is denoted as $\bar{d}$. The free length of highway with m trucks on the highway length ℓ is given by $\ell - m\bar{d} = \ell(1.0 - m\bar{d}/\ell)$. The adjusted free length is denoted by ℓ_m and calculated as follows:

$$\ell_m = \ell(1.0 - m\bar{d}/\ell)^{\beta} > 0.0 \qquad (3)$$

where β is the length parameter ($\beta > 0.0$). If parameter β is set to zero, the distribution described below reverts to a basic Poisson distribution. As parameter β increases the adjusted free length decreases and the probability of multiple presence decreases.

Both the following probabilities are calculated conditional on one truck in a fixed location and the two probabilities are assumed to be equal:

- the probability of m or more trucks on length ℓ, and
- the probability of m or more trucks of zero length on the adjusted free highway length ℓ_m.

The latter probability is denoted by P_m^* and calculated using Equation 1; vehicles of zero length are the implicit assumption of a basic Poisson distribution. Thus, the probabilities P_1^*, P_2^* and P_m^* are as follows where

m is three or more:

$$P_1^* = 1.0; \quad P_2^* = 1.0 - \exp\{-\frac{\ell_1}{\bar{x}}\}$$

$$P_m^* = 1.0 - \exp\{-\frac{\ell_{m-1}}{\bar{x}}\} \left[1.0 + \sum_{n=2}^{m-1} \frac{(\ell_{m-1})^{n-1}}{(n-1)!}\right] \quad (4)$$

The modified Poisson probability of exactly m trucks present on length ℓ conditional on a truck at a fixed location is given by:

$$\tilde{P}_m = P_m^* - P_{m+1}^* \quad (5)$$

From Equation 3, it is seen that if the number of trucks present is so large that $m\bar{d} > \ell$, the adjusted free length $\ell_m = 0$; from Equation 4, $P_m^* = 0$ and $P_{m+1}^* = 0$; thus, from Equation 5, $\tilde{P}_m = 0$. The modified Poisson distribution gives an exactly zero probability to events which indicate more trucks present than the number which would completely fill the specified highway length.

3/ COUNTING MULTIPLE PRESENCE

During the multiple presence studies done in 1982 and 1983 [5, 6], the times were recorded when the front of each vehicle arrived at two sensors (induction coils or loops) approximately 16 m apart. Using the recorded times and distance, the speed of each vehicle was calculated. The time between vehicle arrivals at the first sensor was recorded also. This interval was multiplied by the speed of the first vehicle and the product was recorded as the headway distance for the first vehicle. Herein, a headway distance is an estimate of the distance between the fronts of two adjacent vehicles.

Vehicle configurations were identified using pictures taken while the data from the traffic sensors were recorded. An event was defined each time a truck arrived at the first sensor. Trucks following the one at the sensor were located by adding headway distances.

If the sum of the headway distances indicated that the front of a truck was on the highway segment of length ℓ, the truck was considered present. When multiple truck presence was counted in two or more lanes, an event was defined each time a truck arrived at the first sensor in any lane.

Multiple presence in simulated congested traffic was counted in a similar manner except that the distance between adjacent vehicles was reduced to 2 m. Each vehicle was identified and a length assigned equal to the average length for the vehicle configuration. The average length for each configuration was determined from a separate study of the pictures taken during Phase II [5].

Two details of the multiple presence counting method require further discussion:

1/ Each event is conditional on the presence of a truck at the first sensor -- that is, at the end of the highway segment of length ℓ. For the same line of traffic, this counting method causes slightly higher frequencies of multiple presence than would occur if the count were conditional upon a truck at the centre of length ℓ. If the Poisson idealization were precisely accurate, the multiple presence

frequencies would be independent of the location chosen to trigger a counting event.

2/ A counting event occurs for each truck. In multiple truck events, each truck is counted in more than one event. For a Poisson idealization, there are identical probability distributions:

- based on one event per truck, and
- based on events which include non-overlapping traffic segments only.

4/ TRUCK HEADWAY SURVEYS

4.1/ The 1981 Survey

The 1981 survey was done at the Shawanaga River bridge on Hwy 69 between Parry Sound and Sudbury on September 30, and October 1, 13, 14, and 15. The traffic was free-moving and travelled between 50 and 90 km/h. Approximately 30 trucks per hour use this two-lane highway with destinations in southern Ontario, northern Ontario and western Canada. The trucks change speed frequently because of changes in grade. Passing is difficult because of curves. Therefore, truck segregation occurs -- trucks tend to travel in groups and motorists in other vehicles are reluctant to travel among them.

Histograms of headway distance in the north- and southbound lanes are shown in Figures 1(a) and 1(b), respectively. In each figure, the mean headway distance $\bar{x}$ is given and the corresponding exponential distribution, Equation 2 with parameter $\bar{x}$, is superimposed on the histogram. From the figures it is seen that the frequency of headway distance does not decrease with distance as rapidly as the negative exponential distribution would indicate.

4.2/ The 1982 Survey

The 1982 survey was done on Keele Street at the Hwy 401 overpass in Downsview on December 13, 14, 15 and 16. The traffic was frequently slow, congested and occasionally stopped because of a stop light beyond the bridge. Approximately 75 trucks per hour use the three southbound lanes which were monitored. Two thirds of the trucks were light two-axle vehicles.

Histograms of headway distance in the three lanes are shown in Figures 2(a), 2(b) and 2(c). In each Figure, the mean headway distance $\bar{x}$ is given and the corresponding exponential distribution, Equation 2 with parameter $\bar{x}$, is superimposed on the histogram.

5/ MULTIPLE TRUCK PRESENCE IN SINGLE LANES

The multiple truck presence data calculated from the 1981 survey on Hwy 69 are listed in Figure 3 and histograms of multiple truck presence for four lane lengths are shown in Figure 4. Figures 3(a) and 4(a) pertain to northbound traffic and Figures 3(b) and 4(b) pertain to southbound traffic.

The multiple truck presence data calculated from the 1982 survey on Keele Street are listed in Figure 5 and histograms of multiple truck presence for four lane lengths are shown in Figure 6. Figures 5(a) and 6(a) pertain to the east lane of traffic; 5(b) and 6(b) pertain to the centre lane, and 5(c) and 6(c) pertain to the west lane.

Each of the above figures have two parts:
i) pertaining to the moving traffic as it was observed, and
ii) pertaining to simulated congested traffic.

To each of the above single lane multiple truck presence studies, the modified Poisson distribution was fitted using an optimization computer program and a least squares objective function. Based on all the data, reasonable values for the mean length occupied by a truck $\bar{d}$ and the length parameter β were determined to be 14 m and 0.3, respectively. For each of the traffic lanes an effective mean truck headway distance was calculated to give a best fit to the data for cases i) and ii) above. The fitted distributions are superimposed on the histograms and the effective mean truck headway distance is given with each figure.

From the results it is seen that in the five lanes of moving traffic, the effective mean truck headway distances were between 1250 and 2530 m. However, when congested traffic was simulated the effective mean truck headway distance on Hwy 69 decreased to between 50 and 54 m while the effective mean truck headway distance on Keele Street decreased to between 113 and 303 m. The traffic on Hwy 69 was 20% trucks travelling with considerable segregation and if the traffic were congested by a stoppage, several trucks on a short highway length would be a frequent occurrence. The traffic on Keele Street was 5% trucks which were well integrated with the light vehicles and if traffic were congested by a stoppage, several trucks on a short highway length would not be as frequent as on Hwy 69.

6/ MULTIPLE TRUCK PRESENCE IN TWO AND THREE LANES

During the study of the three southbound lanes of traffic on Keele Street, vehicles could change from one lane to another; therefore, the independence of the three lanes of traffic is questionable. The multiple truck presence in more than one lane is presented as follows:

- For trucks in the east and centre lanes, multiple presence is listed in Figure 7(a) and histograms of multiple presence for four lane lengths are shown in Figure 8(a).

- For trucks in the centre and west lanes, multiple presence is listed in Figure 7(b) and histograms of multiple presence are shown in Figure 8(b).

- For trucks in the east, centre and west lanes, multiple presence is listed in Figure 7(c) and histograms of multiple presence are shown in Figure 8(c).

Each of the above figures has two parts:
i) pertaining to the moving traffic as it was observed, and
ii) pertaining to simulated congested traffic.

To each of the above studies of multiple truck presence, the modified Poisson distribution was fitted. Again, the length occupied by a truck $\bar{d}$ and the length parameter β were taken as 14 m and 0.3, respectively. To account for the additional space available for trucks, the ratio in Equation 3, $m\bar{d}/\ell$, was taken as $m\bar{d}/2\ell$ for two lanes studied together and $m\bar{d}/3\ell$ for three lanes studied together.

The fitted distributions are superimposed on the histograms in Figure 8 and the effective mean truck headway distance is given with each figure.

If the lanes of traffic were independent and the Poisson idealization of traffic flow were accurate, multiple presence in two or more lanes could be calculated using a Poisson distribution with an arrival rate equal to the sum of the arrival rates for the individual lanes. This relationship follows from the regenerative characteristic of the Poisson distribution.

The arrival rates of the single lanes studied were taken as the reciprocals of the effective mean truck headway distances obtained by fitting distributions to the data. These effective mean headway distances are given in Figure 6.

The arrival rates were added and a "combined mean truck headway distance" was calculated as the reciprocal of the sum. In Figure 9, the combined mean truck headway distances are listed along with the effective mean truck headway distances obtained by fitting distributions to the data. From Figure 9, it is seen that the calculated value is fairly close to the fitted value for the simulated congested traffic data, but the calculated value always overestimates the fitted value for the case of moving traffic. Thus, in the moving traffic case, multiple truck presence is more common than the modified Poisson distribution would indicate if the combined mean truck headway distance were used as the parameter of the distribution.

One possible explanation for this observation is that multiple truck presence in the adjacent lanes had positive dependence.

5/ CONCLUSIONS

1/ The multiple truck presence data obtained during the 1981 and 1982 surveys can be fitted with reasonable accuracy by the modified Poisson distribution described by Equations 3, 4 and 5. The modified distribution takes into account the average length occupied by a truck and a zero probability is given to impossible events which include more trucks than would fill the specified highway length. Based on fitting distributions to the data, 14 m was found to be a reasonable value to assign as the length occupied by an average truck. On the same basis, the length parameter β in Equation 3 was set at 0.3.

2/ In order to fit modified Poisson distributions to the data, effective mean truck headway distances were calculated. These values correspond only approximately to the mean headway distances calculated directly. Both values are listed in Figure 9 for the Keele Street data. Values for the Hwy 69 data are in Figures 1 and 4. One reason for these discrepancies is that a Poisson process is not a precisely accurate idealization for truck traffic.

3/ For adjacent lanes of traffic travelling in one direction, on the basis of assumed independence, it is convenient to add truck arrival rates in the individual lanes and calculate multiple truck presence using the sum of the rates. Based on the data from the 1982 survey on Keele Street, this assumption would appear to underestimate multiple truck presence in moving traffic and to give approximately correct results for simulated congested traffic.

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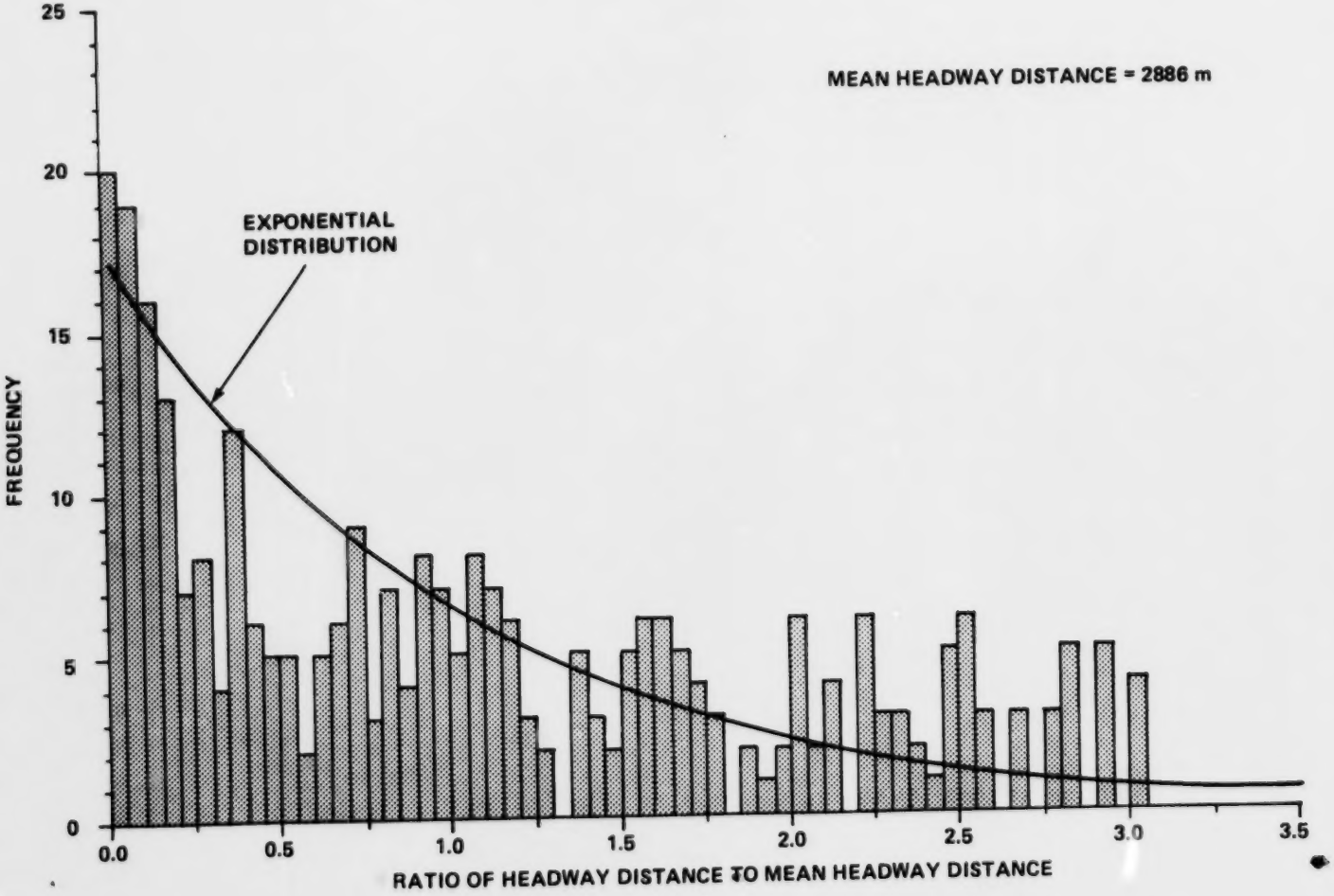

Figure 1(a)/ Histogram of Headway Distance for Trucks Northbound on Hwy 69

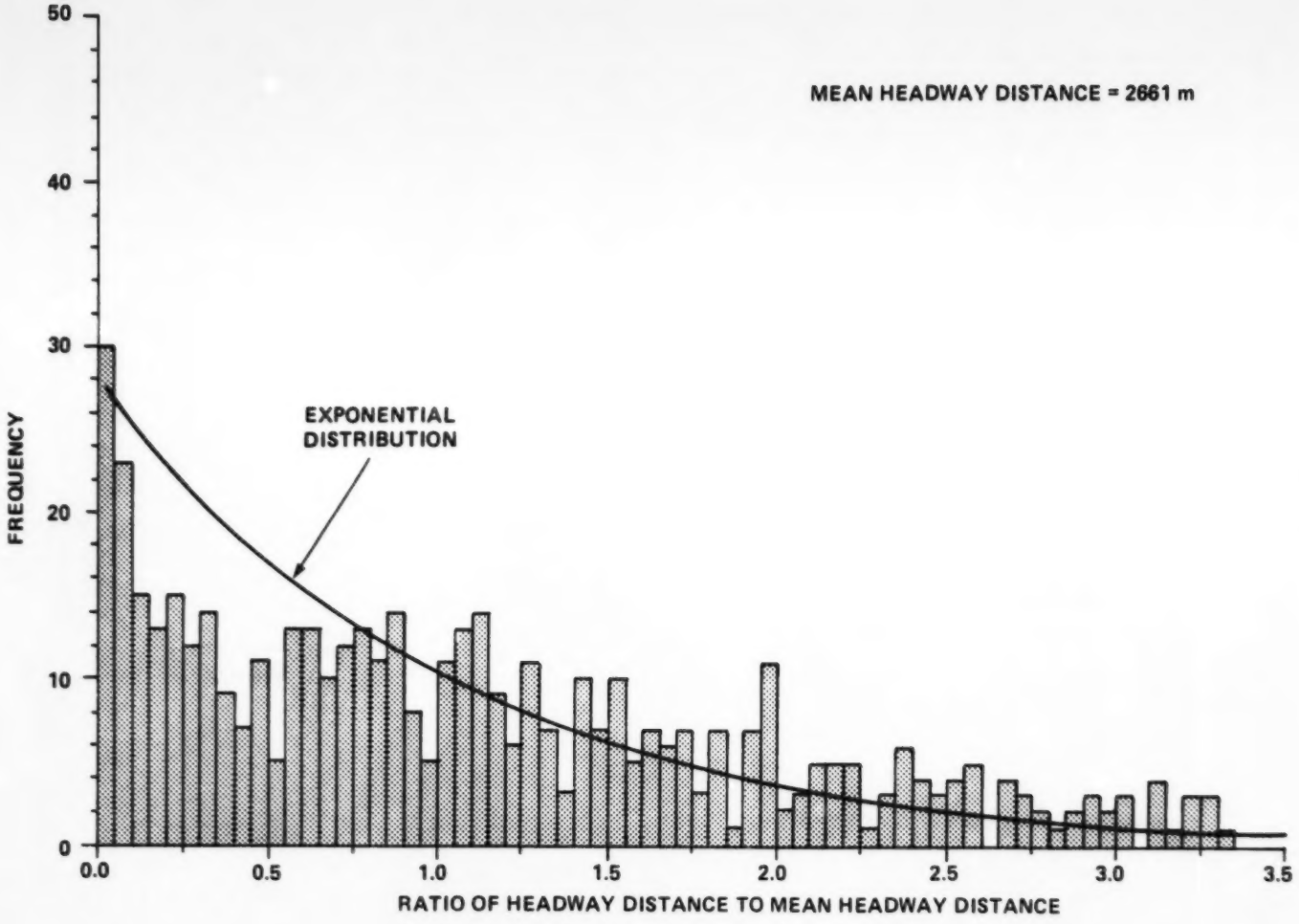

Figure 1(b)/ Histogram of Headway Distance for Trucks Southbound on Hwy 69

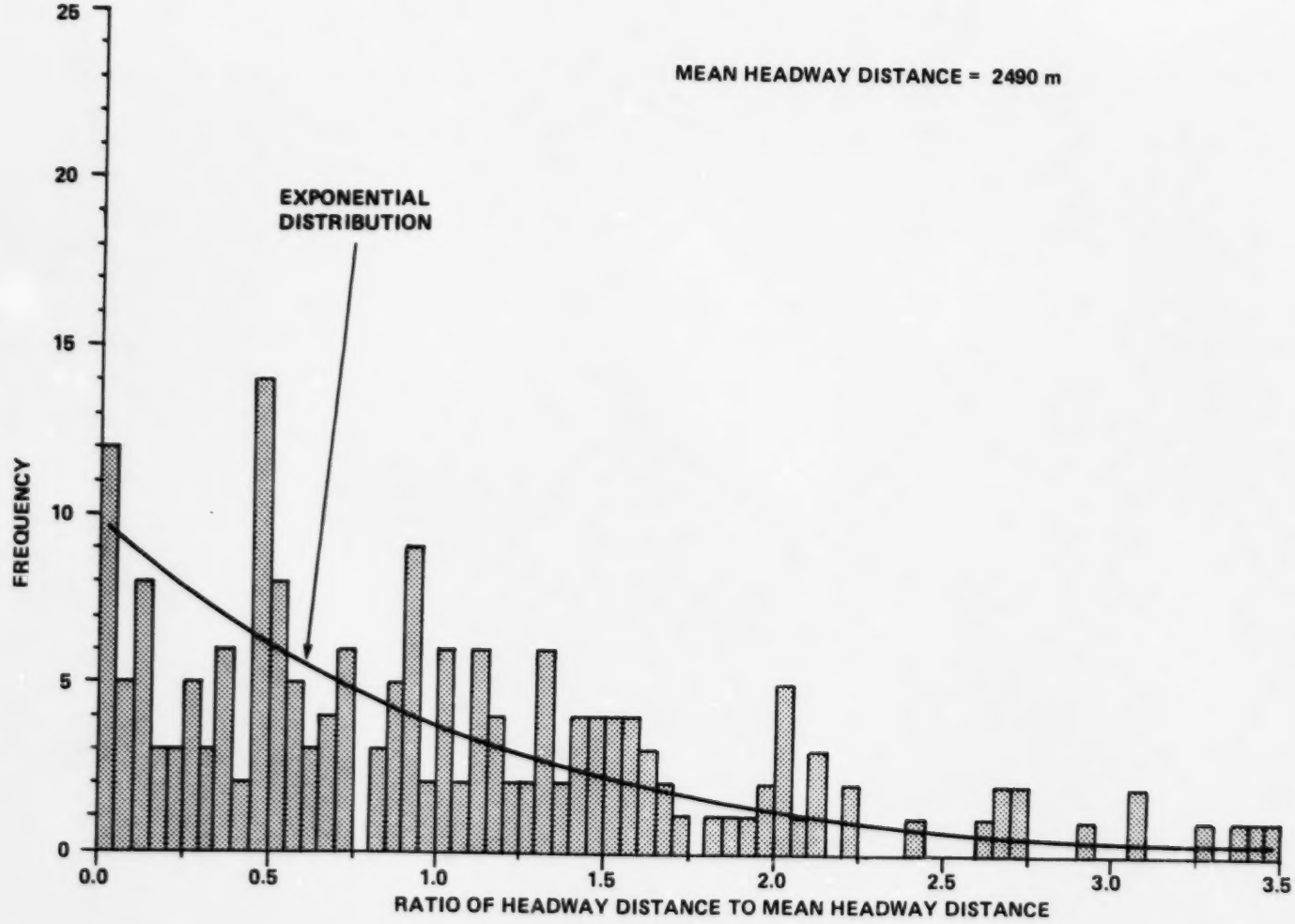

Figure 2(a)/ Histogram of Headway Distance for Trucks in the Southbound East Lane of Keele Street

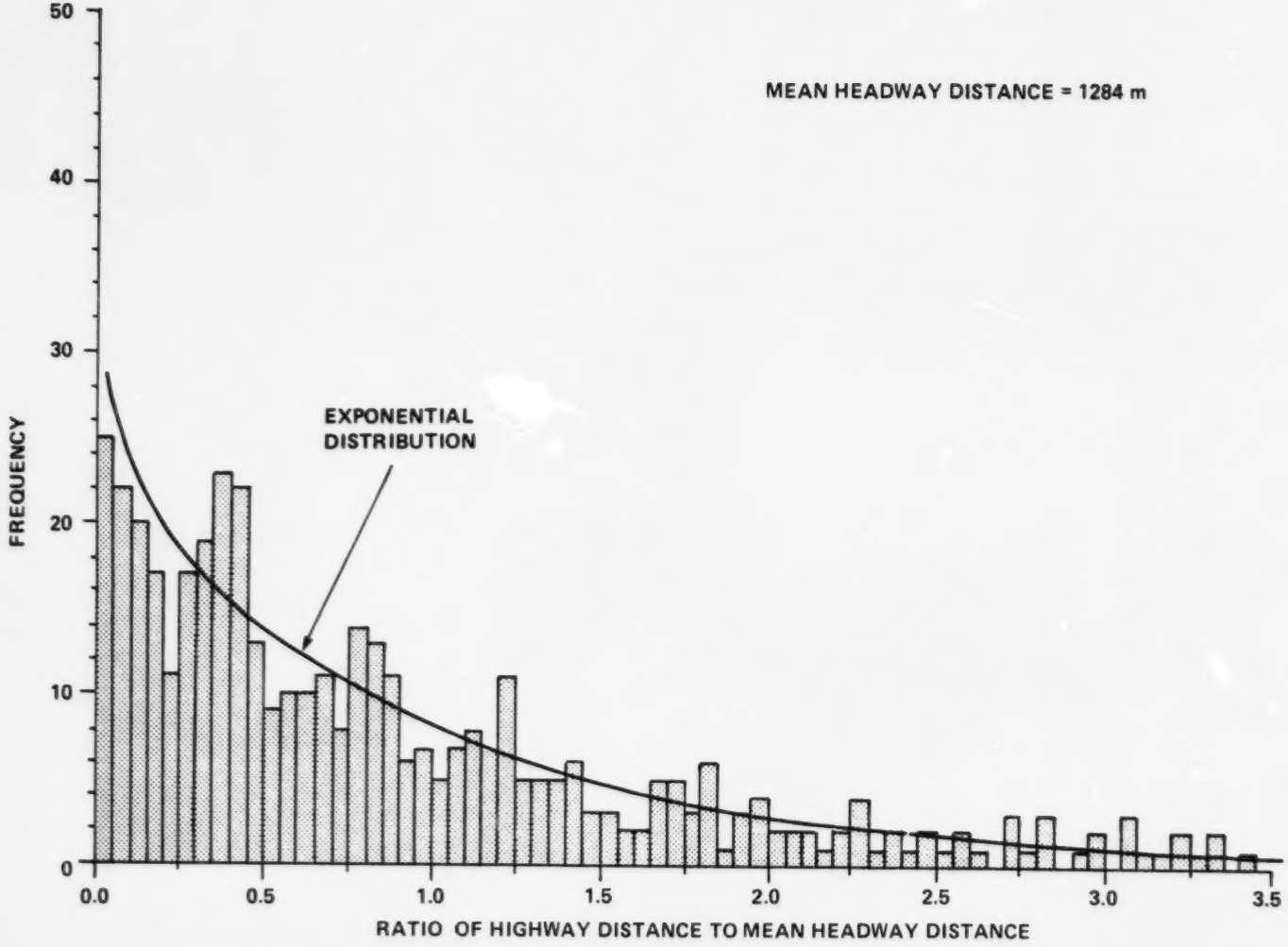

Figure 2(b)/ Histogram of Headway Distance for Trucks in the Southbound Centre Lane of Keele Street

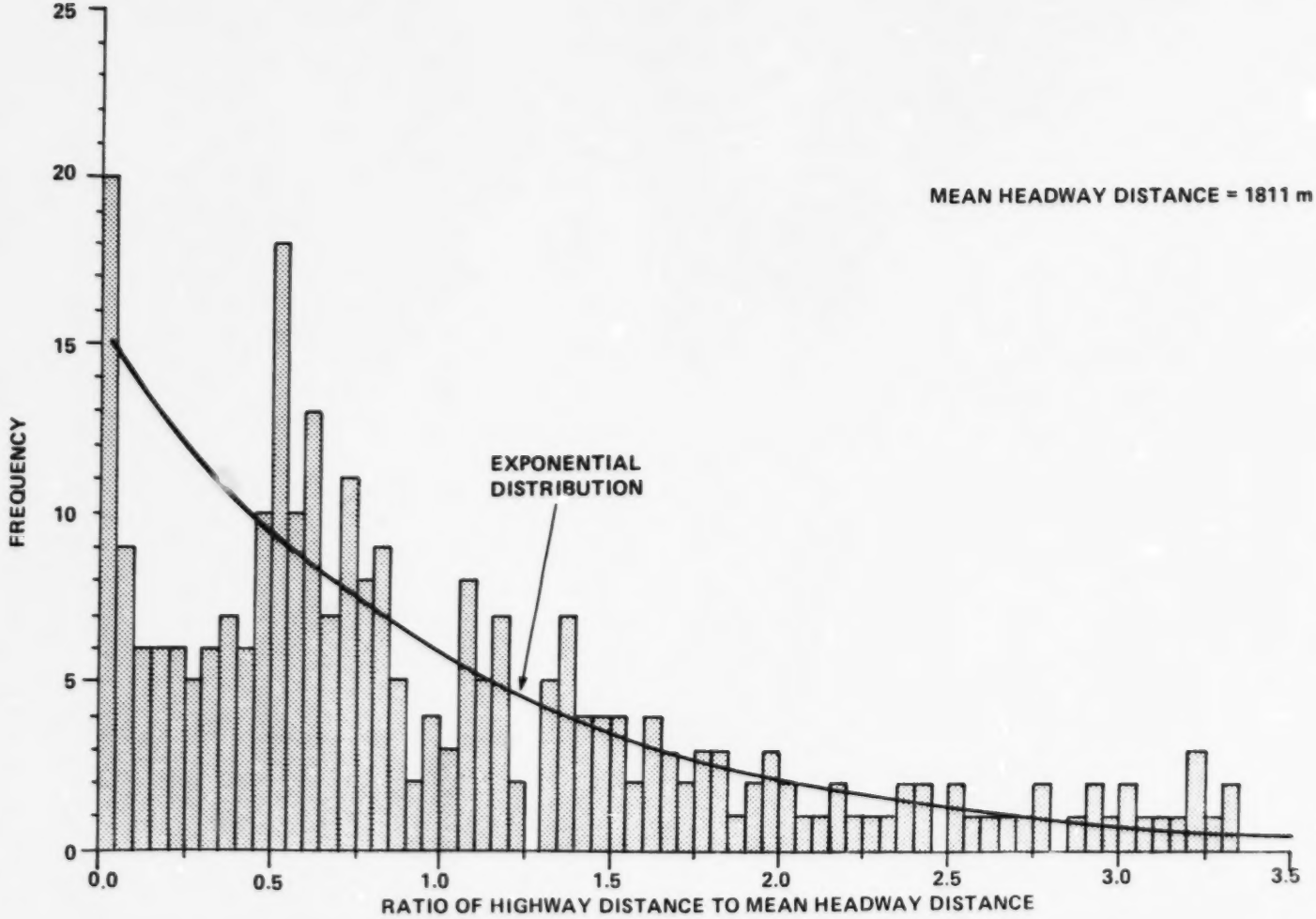

Figure 2(c)/ Histogram of Headway Distance for Trucks in the Southbound West Lane of Keele Street

i) Moving Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	461	439	432	422	413	412	403	399	390	386
2	14	36	41	51	59	59	67	70	76	79
3			2	2	3	4	5	6	9	10

ii) Simulated Congested Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	203	80	28	12	5	2	2	2	2	
2	213	151	91	48	24	8	3	3	2	1
3	56	146	126	91	58	41	16	8	5	4
4	3	80	107	101	92	64	48	29	13	9
5		18	82	88	75	71	66	49	28	21
6			37	71	84	73	67	57	58	34
7			4	47	58	85	66	70	58	44
8				17	47	40	71	56	71	67
9					24	51	49	56	49	60
10					8	23	32	59	55	52
11						15	31	20	40	58
12						2	18	34	26	34
13							6	19	19	22
14								11	31	16
15								2	12	22
16									6	21
17										8
18										2

Figure 3(a)/ Frequencies of Multiple Presence of Trucks Northbound on Hwy 69

i) Moving Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	676	631	605	591	580	573	564	557	554	547
2	8	52	78	84	90	92	101	105	108	115
3	1	2	2	10	15	18	15	18	17	17
4						2	5	5	3	2
5									3	4

ii) Simulated Congested Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	318	106	38	10	8					
2	305	249	135	64	20	17	2	1	1	
3	62	217	201	156	78	32	23	6	2	
4		96	179	177	149	86	54	31	9	5
5		17	93	149	157	149	95	57	36	17
6			35	80	134	147	140	104	69	35
7			4	37	87	116	126	141	114	86
8				11	34	73	109	115	134	112
9				1	14	42	74	90	110	126
10					4	17	34	77	74	112
11						5	16	31	71	64
12						1	8	19	33	58
13							4	6	18	38
14								6	7	19
15								1	2	6
16									5	4
17										2
18										1

Figure 3(b)/ Frequencies of Multiple Presence of Trucks Southbound on Hwy 69

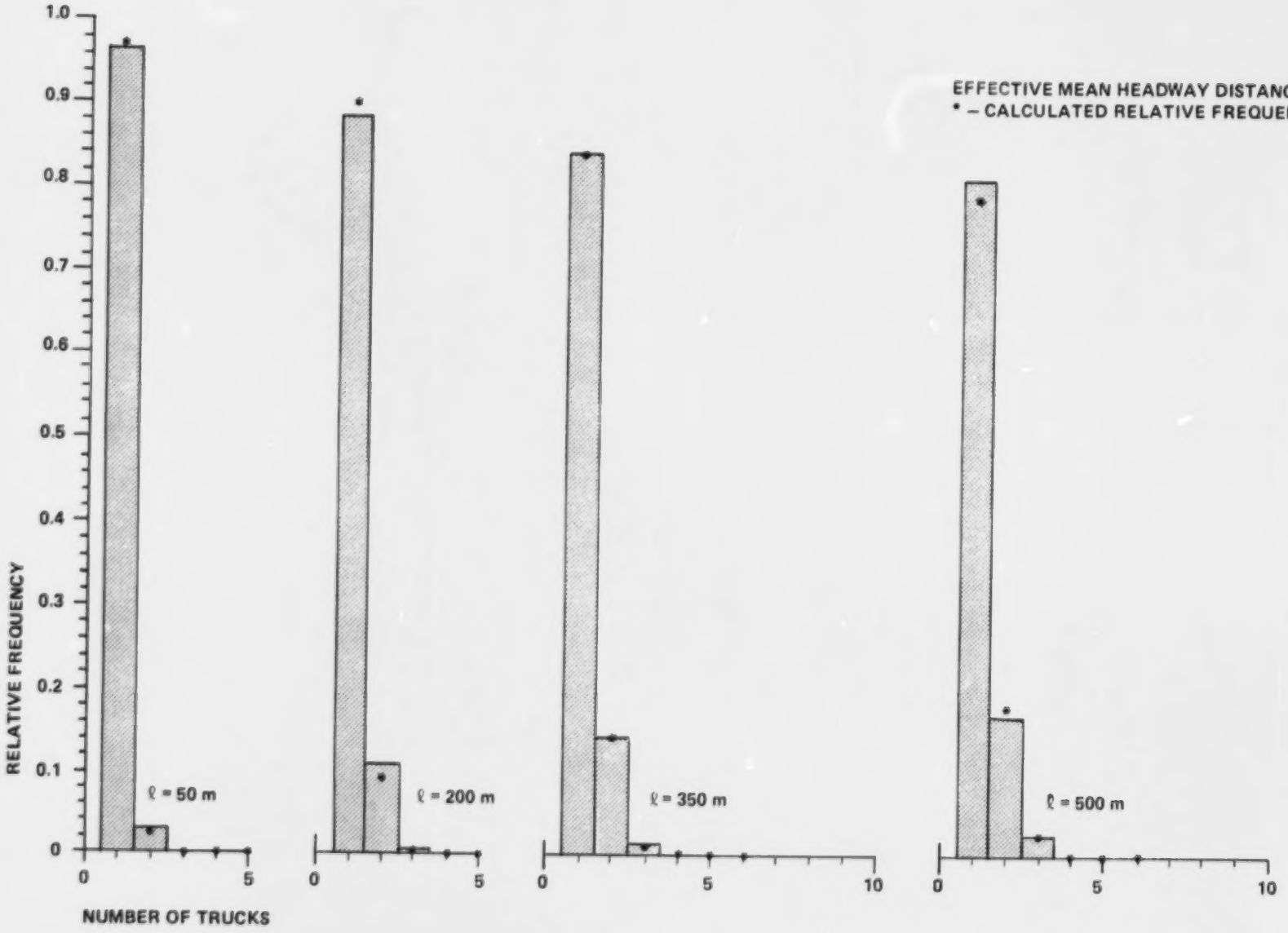

Figure 4(a) I/ Histograms of Multiple Truck Presence on Hwy 69, Northbound in Moving Traffic

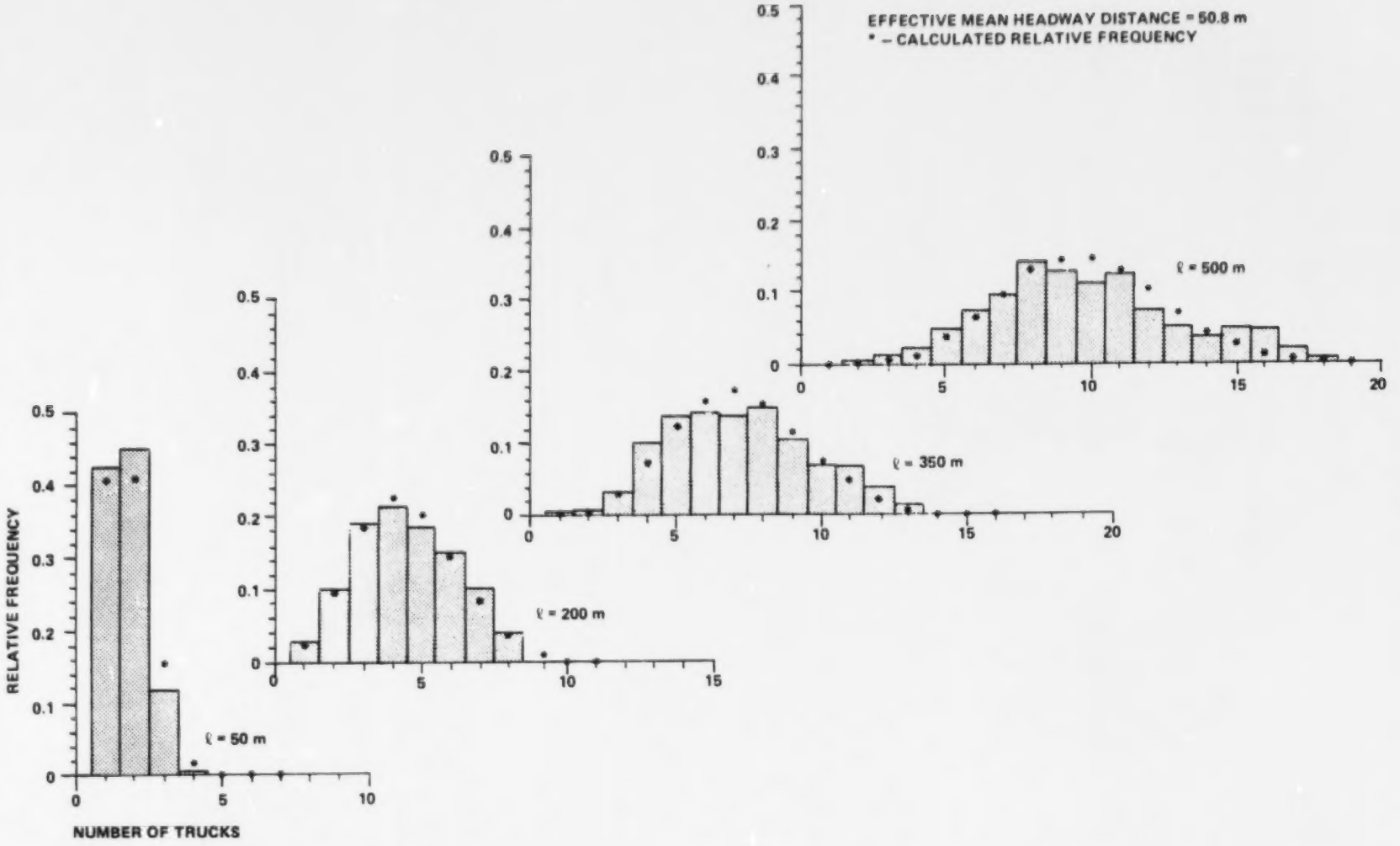
EFFECTIVE MEAN HEADWAY DISTANCE = 50.8 m
* – CALCULATED RELATIVE FREQUENCY
RELATIVE FREQUENCY
NUMBER OF TRUCKS
ℓ = 50 m
ℓ = 200 m
ℓ = 350 m
ℓ = 500 m

Figure 4(a) II/ Histograms of Multiple Truck Presence on Hwy 69, Northbound in Simulated Congested Traffic

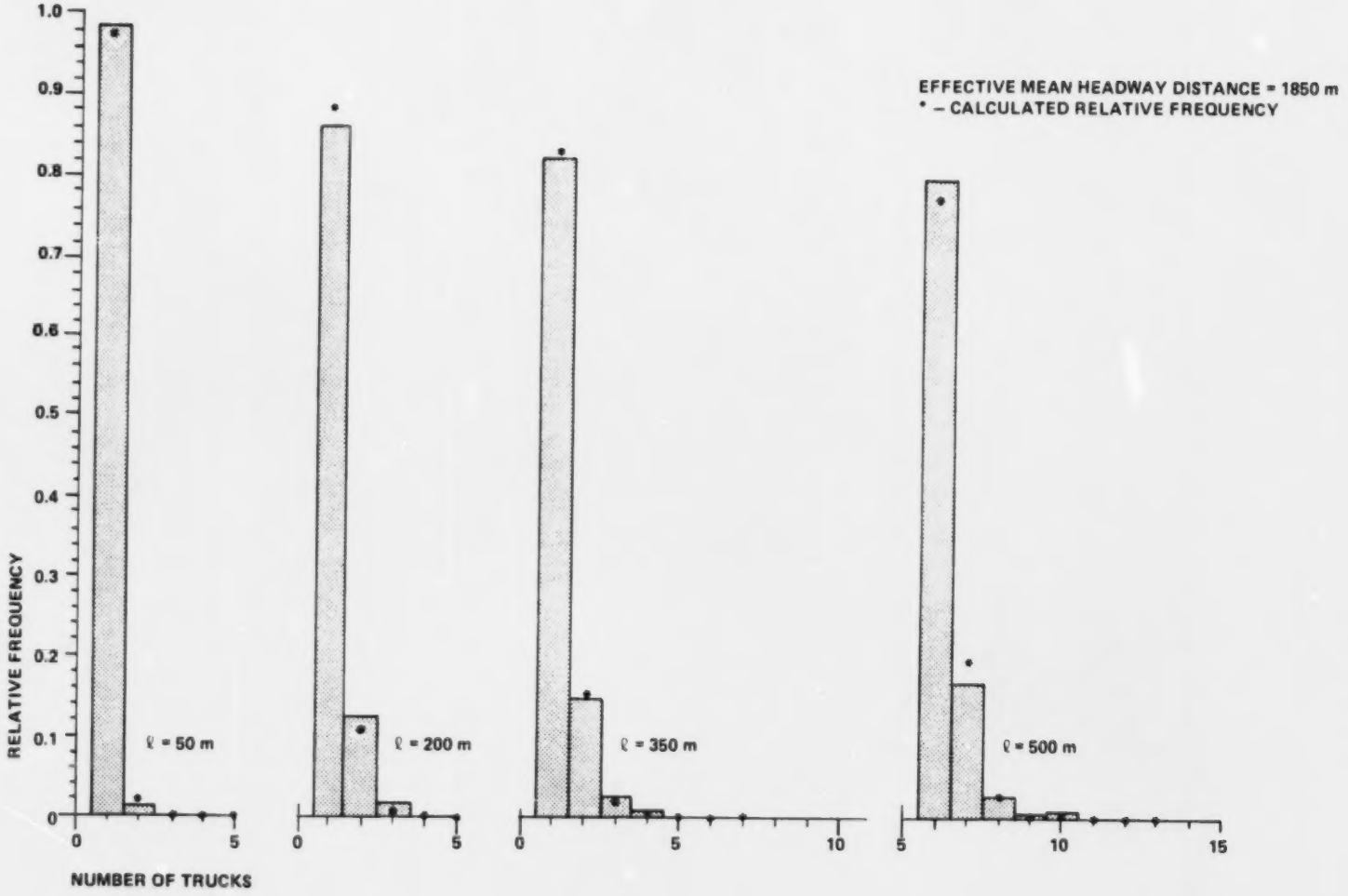

Figure 4(b) I/ Histograms of Multiple Truck Presence on Hwy 69, Southbound in Moving Traffic

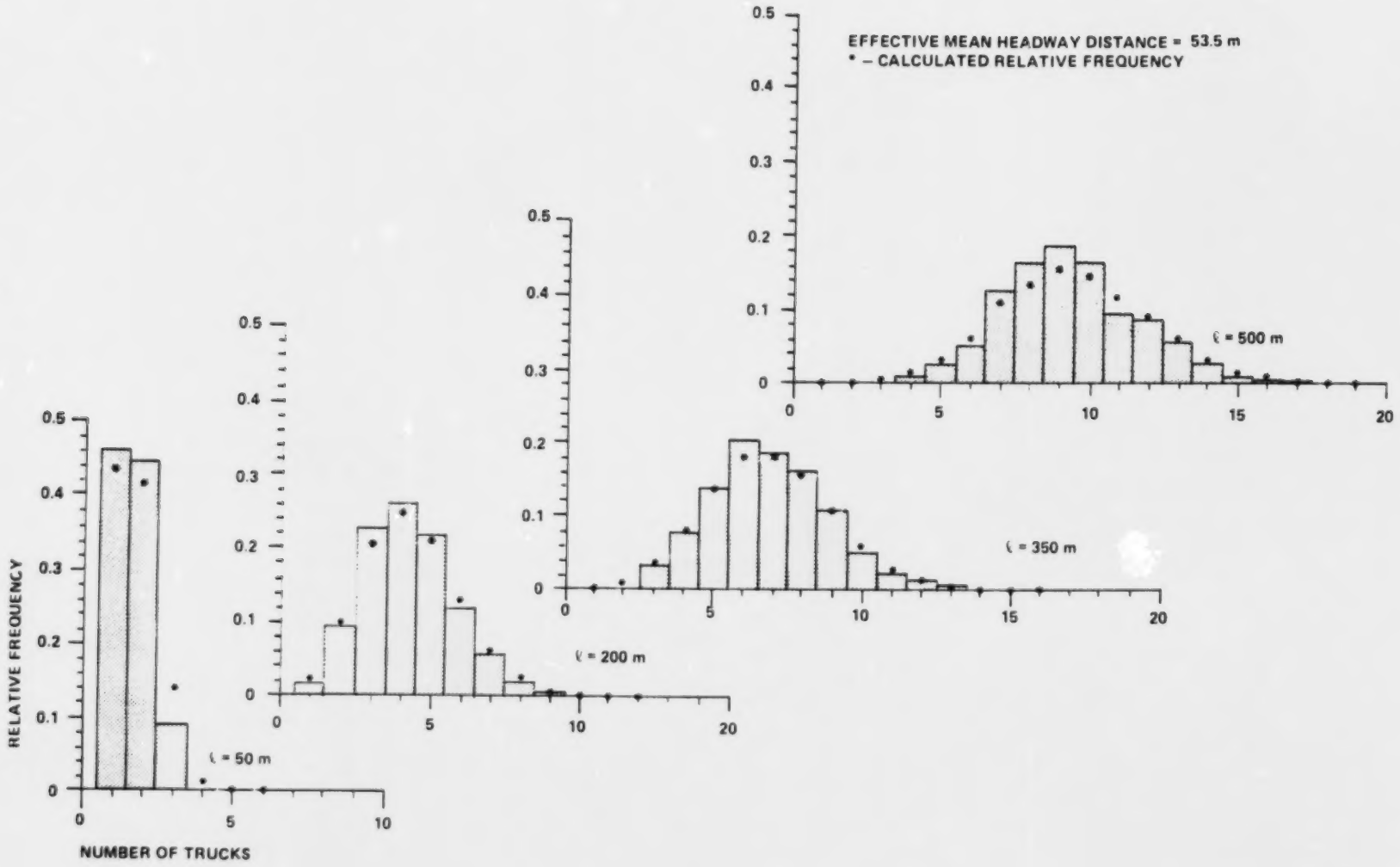
EFFECTIVE MEAN HEADWAY DISTANCE = 53.5 m
* – CALCULATED RELATIVE FREQUENCY
RELATIVE FREQUENCY
NUMBER OF TRUCKS
ℓ = 50 m
ℓ = 200 m
ℓ = 350 m
ℓ = 500 m

Figure 4(b) II/ Histograms of Multiple Truck Presence on Hwy 69, Southbound in Simulated Congested Traffic

i) Moving Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	300	282	272	264	260	256	252	246	245	242
2	13	31	39	42	45	49	53	58	59	60
3	1	1	2	7	7	7	7	8	8	10
4			1	1	2	1	1	1	1	1
5						1	1	1	1	1

ii) Simulated Congested Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	255	207	153	113	90	67	52	37	28	23
2	60	84	115	122	113	113	93	80	77	59
3	3	21	39	62	73	75	89	92	79	79
4	1	5	7	13	28	38	49	61	63	74
5		2	3	4	8	16	23	30	45	39
6			2	5	4	6	8	13	14	27
7					3	3	3	3	9	10
8						1	2	2	3	5
9								1	1	3

Figure 5(a)/ Frequencies of Multiple Presence of Trucks on Southbound Keele Street, West Lane

i) Moving Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	455	432	411	397	383	368	360	348	336	320
2	14	37	56	69	82	91	93	101	109	118
3	1	1	3	4	5	11	16	19	23	30
4							1	2	2	2

ii) Simulated Congested Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	324	213	141	88	55	42	33	23	16	10
2	136	171	164	158	130	100	77	58	47	34
3	15	71	106	114	126	118	98	100	80	70
4		18	49	73	85	93	97	86	96	97
5		2	11	30	50	70	79	80	71	68
6			4	8	18	29	53	59	60	66
7				4	7	15	19	43	49	50
8					4	6	16	16	37	37
9						2	2	8	12	27
10							1	2	6	12
11									1	4

Figure 5(b)/ Frequencies of Multiple Presence of Trucks on Southbound Keele Street, Centre Lane

i) Moving Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	202	198	192	190	183	180	178	176	174	170
2	4	8	14	15	21	23	23	25	27	29
3				1	2	3	5	5	5	6

ii) Simulated Congested Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	184	162	140	118	90	77	64	50	44	32
2	24	39	54	65	87	83	85	86	76	75
3	3	10	15	23	26	40	38	45	53	56
4			2	5	7	9	19	21	24	26
5					1	2	4	6	11	18
6							1	2	1	2
7								1	2	1
8										1

Figure 5(c)/ Frequencies of Multiple Presence of Trucks on Southbound Keele Street, East Lane

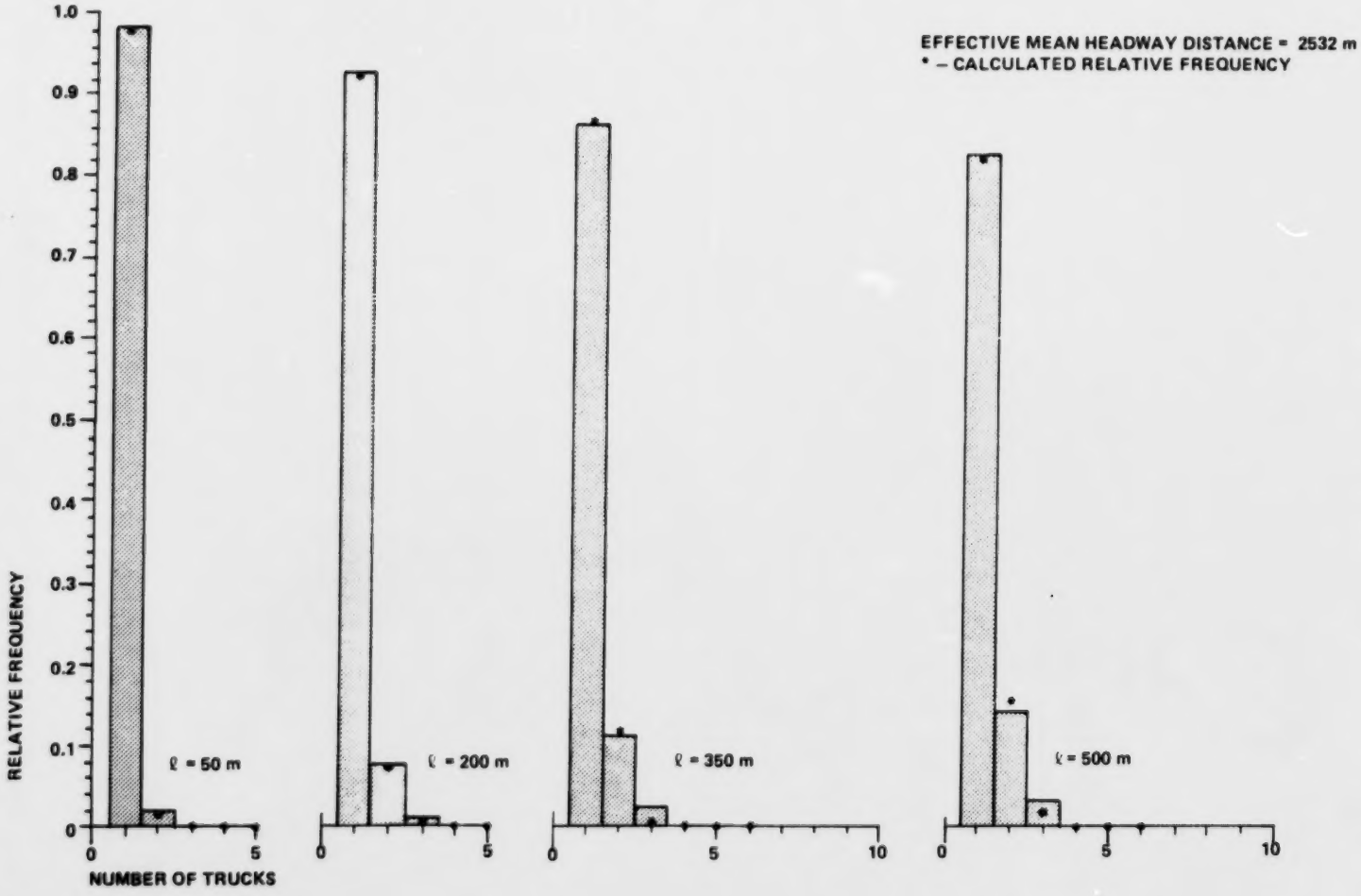

Figure 6(a) I/ Histograms of Multiple Truck Presence on Keele Street, East Lane in Moving Traffic

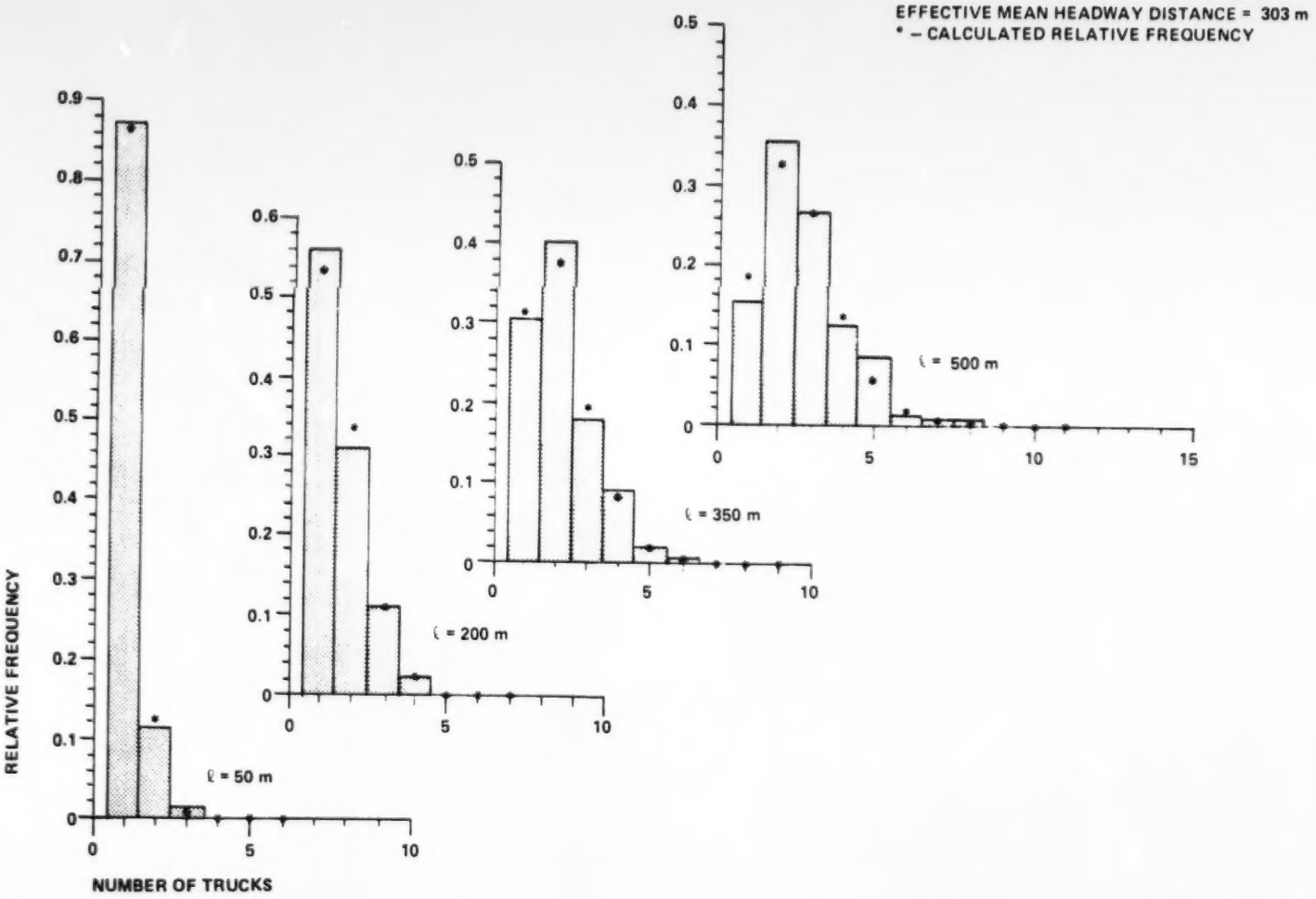
EFFECTIVE MEAN HEADWAY DISTANCE = 303 m
* – CALCULATED RELATIVE FREQUENCY
RELATIVE FREQUENCY
NUMBER OF TRUCKS
ℓ = 50 m
ℓ = 200 m
ℓ = 350 m
ℓ = 500 m

Figure 6(a) II/ Histograms of Multiple Truck Presence on Keele Street, East Lane in Simulated Congested Traffic

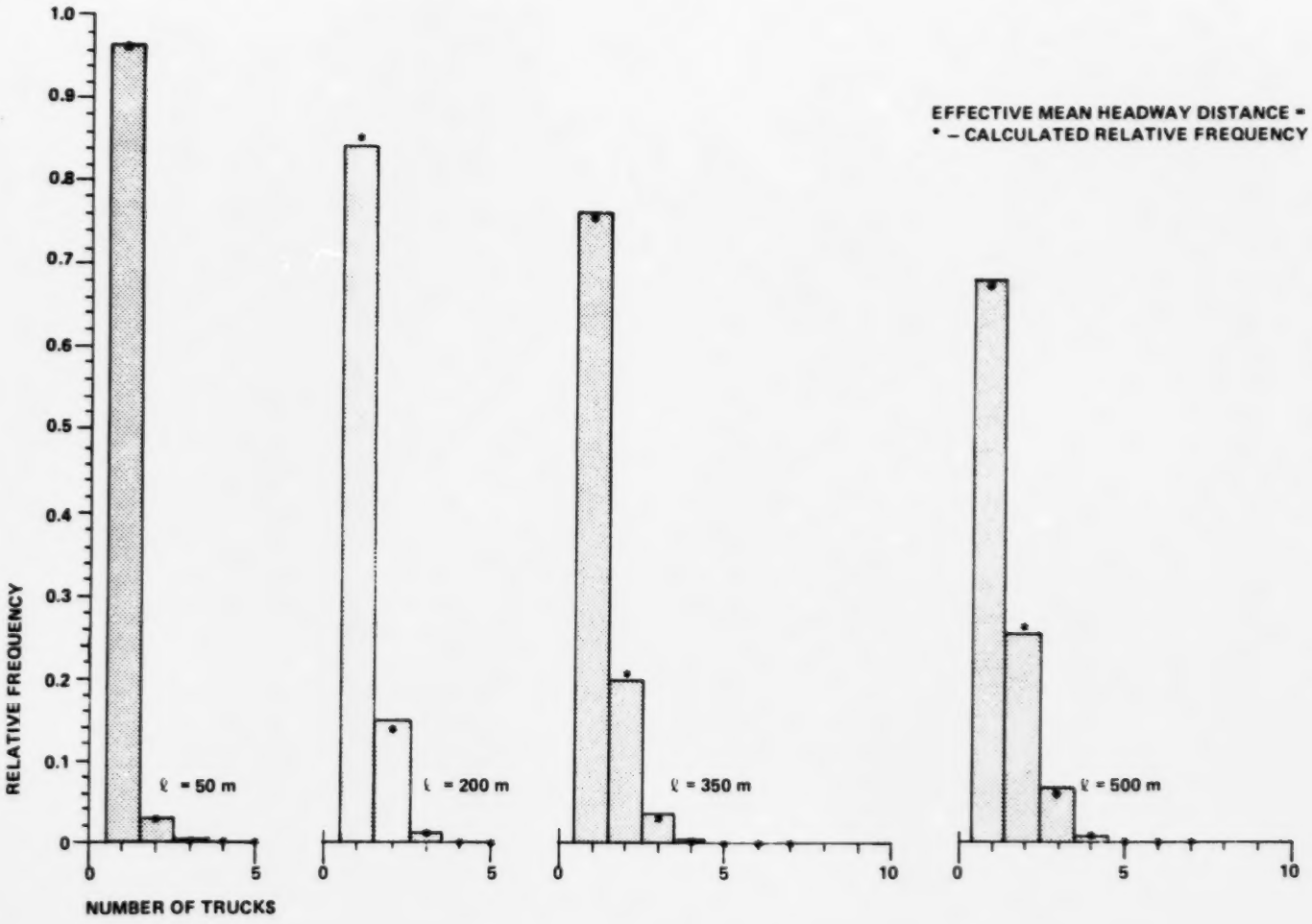

Figure 6(b) I/ Histograms of Multiple Truck Presence on Keele Street, Centre Lane in Moving Traffic

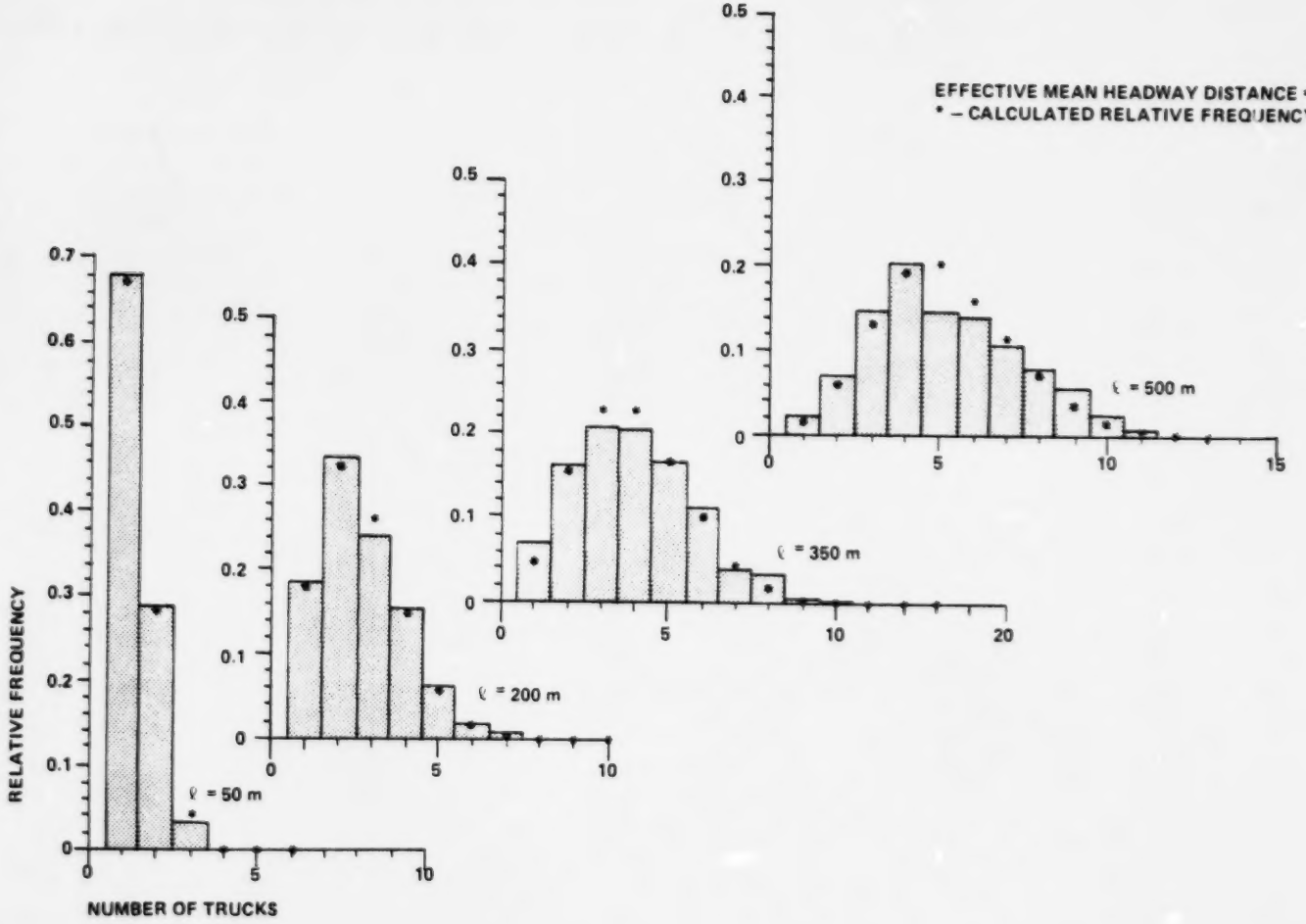
EFFECTIVE MEAN HEADWAY DISTANCE = 114 m
* – CALCULATED RELATIVE FREQUENCY
RELATIVE FREQUENCY
NUMBER OF TRUCKS
ℓ = 50 m
ℓ = 200 m
ℓ = 350 m
ℓ = 500 m

Figure 6(b) II/ Histograms of Multiple Truck Presence on Keele Street, East Lane in Moving Traffic

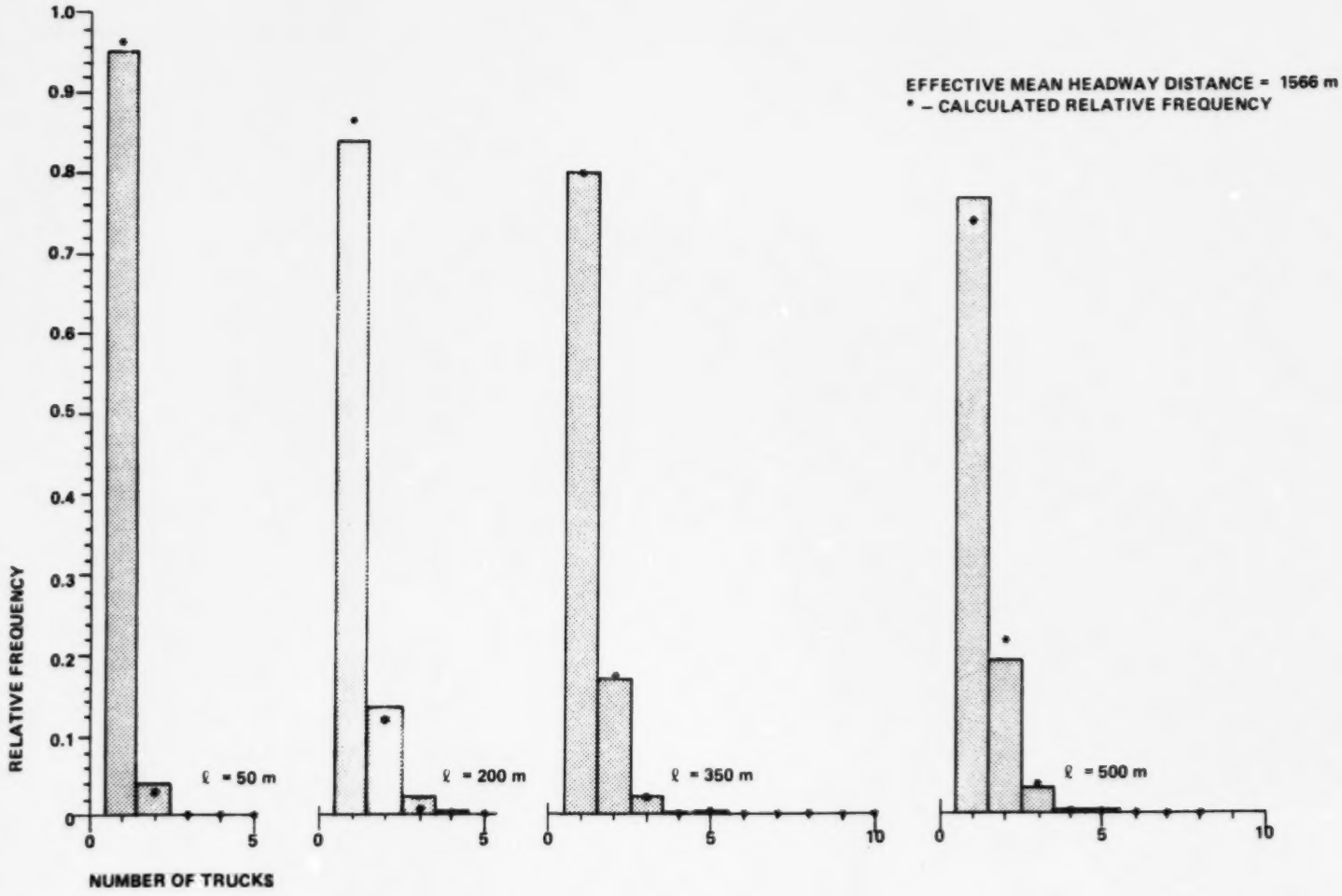

Figure 6(c) I/ Histograms of Multiple Truck Presence on Keele Street, West Lane in Moving Traffic

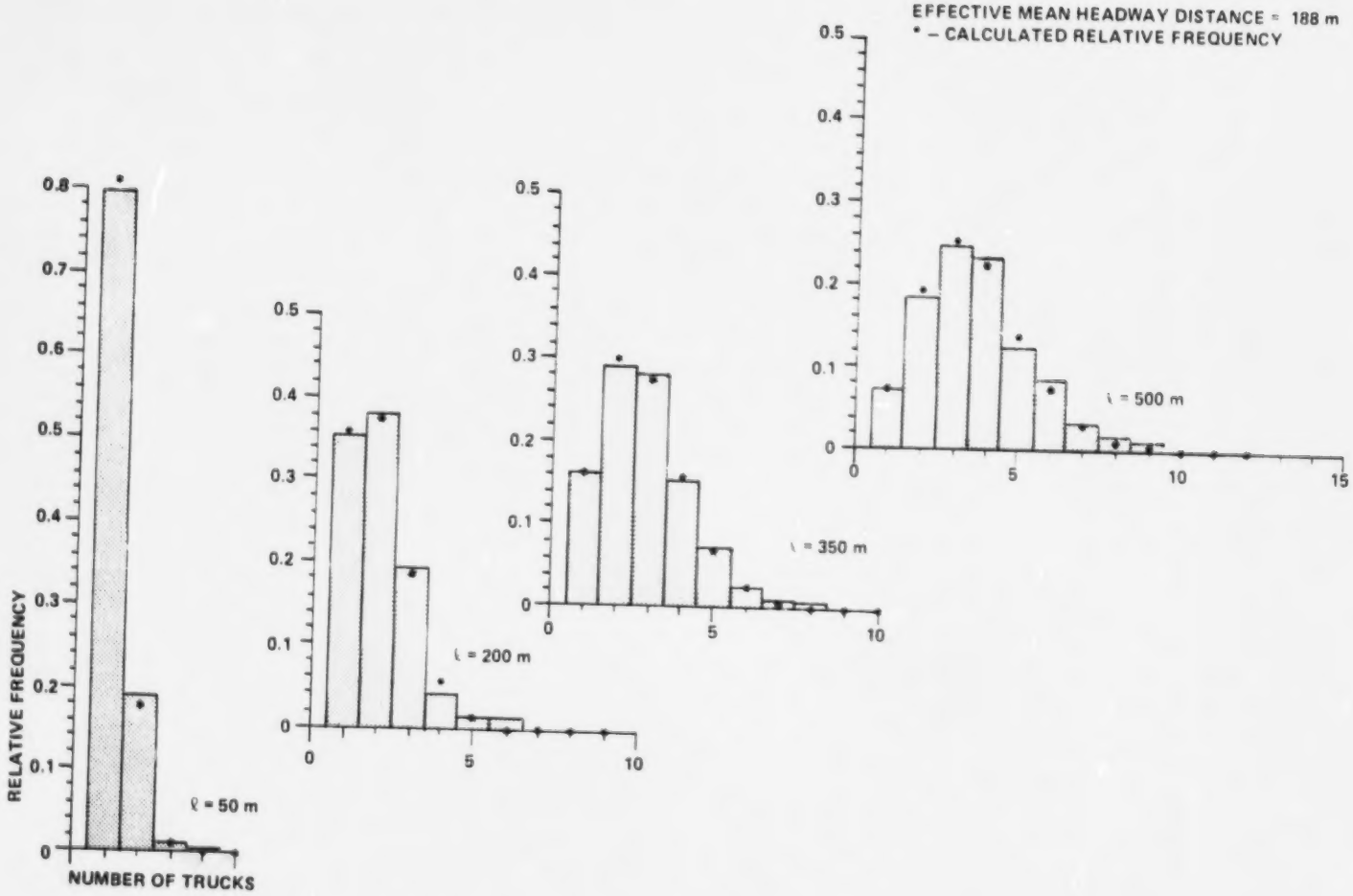
EFFECTIVE MEAN HEADWAY DISTANCE = 188 m
* – CALCULATED RELATIVE FREQUENCY
RELATIVE FREQUENCY
NUMBER OF TRUCKS
ℓ = 50 m
ℓ = 200 m
ℓ = 350 m
ℓ = 500 m

Figure 6(c) II/ Histograms of Multiple Truck Presence on Keele Street, West Lane in Simulated Congested Traffic

i) Moving Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	721	647	589	551	529	504	487	462	440	415
2	63	122	162	184	192	202	203	220	232	242
3	5	20	35	43	53	64	76	77	83	89
4			2	8	10	13	17	22	25	32
5				2	4	2	2	4	4	5
6						2	2	1	1	1
7						1	1	1	1	1
8								1	1	1

ii) Simulated Congested Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	512	283	139	75	43	27	17	12	9	5
2	225	272	251	194	127	82	60	33	30	24
3	46	165	207	192	182	141	102	84	51	36
4	9	48	114	160	162	168	147	119	98	77
5	2	19	47	88	123	132	134	145	125	101
6		6	23	49	80	95	114	123	121	126
7		1	9	21	41	73	83	78	97	98
8			2	12	21	28	61	77	83	98
9			2	1	7	30	31	44	70	63
10				2	6	7	21	35	39	56
11					2	7	12	18	25	36
12						3	7	14	23	28
13						1	4	5	13	22
14							1	4	4	13
15								2	4	5
16								1	1	3
17									1	2
18										1

Figure 7(a)/ Frequencies of Multiple Presence of Trucks on Southbound Keele Street, Centre and West Lanes

i) Moving Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	636	580	538	512	481	460	438	423	402	380
2	43	91	120	135	157	168	179	181	184	191
3	2	10	23	31	38	43	47	58	70	77
4				3	5	10	17	16	19	25
5								3	5	5

ii) Simulated Congested Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	457	260	151	86	53	29	21	14	7	6
2	189	253	237	180	125	95	68	44	35	18
3	35	116	153	185	182	151	115	90	65	48
4	5	48	91	110	131	141	129	129	108	93
5		8	37	76	92	114	124	112	111	105
6		1	13	30	61	75	100	95	115	107
7			4	13	25	42	63	85	78	97
8				4	8	20	35	55	71	76
9				2	5	10	16	30	40	51
10					4	6	10	20	26	35
11						2	2	9	16	25
12						1	3	2	12	17
13								1	2	7
14										1

Figure 7(b)/ Frequencies of Multiple Presence of Trucks on Southbound Keele Street, East and Centre Lanes

i) Moving Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	875	763	680	633	590	557	530	499	469	441
2	109	191	238	251	272	278	283	296	305	308
3	16	40	68	87	94	111	118	129	138	156
4		6	13	21	32	39	48	50	58	60
5			1	6	7	7	13	15	16	20
6				1	3	2	2	5	5	6
7					1	2	2	1	2	2
8						2	1	1	1	1
9							1	1	1	1
10								1	1	1

ii) Simulated Congested Traffic

Number of Trucks:	Lane Length (km)									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
1	612	306	141	68	34	13	8	6	4	3
2	303	343	287	195	120	69	41	21	14	7
3	71	219	257	235	204	150	93	59	35	21
4	16	93	175	190	195	187	161	115	74	55
5	3	25	79	150	173	170	164	155	137	98
6		10	34	84	114	149	146	156	141	140
7		5	18	45	76	98	131	131	133	133
8		3	7	22	46	73	97	109	121	121
9		1	3	9	22	38	62	89	98	112
10			2	3	14	29	45	52	82	85
11			2	1	3	17	18	51	58	67
12				2	1	7	18	19	41	52
13				1	2	2	13	20	24	32
14					1	2	3	12	18	31
15						1	4	4	14	20
16							1	3	5	17
17								1	1	4
18								2	3	3
19									1	1
20									1	1
21										2

Figure 7(c)/ Frequencies of Multiple Presence of Trucks on Southbound Keele Street, East, Centre and West Lanes

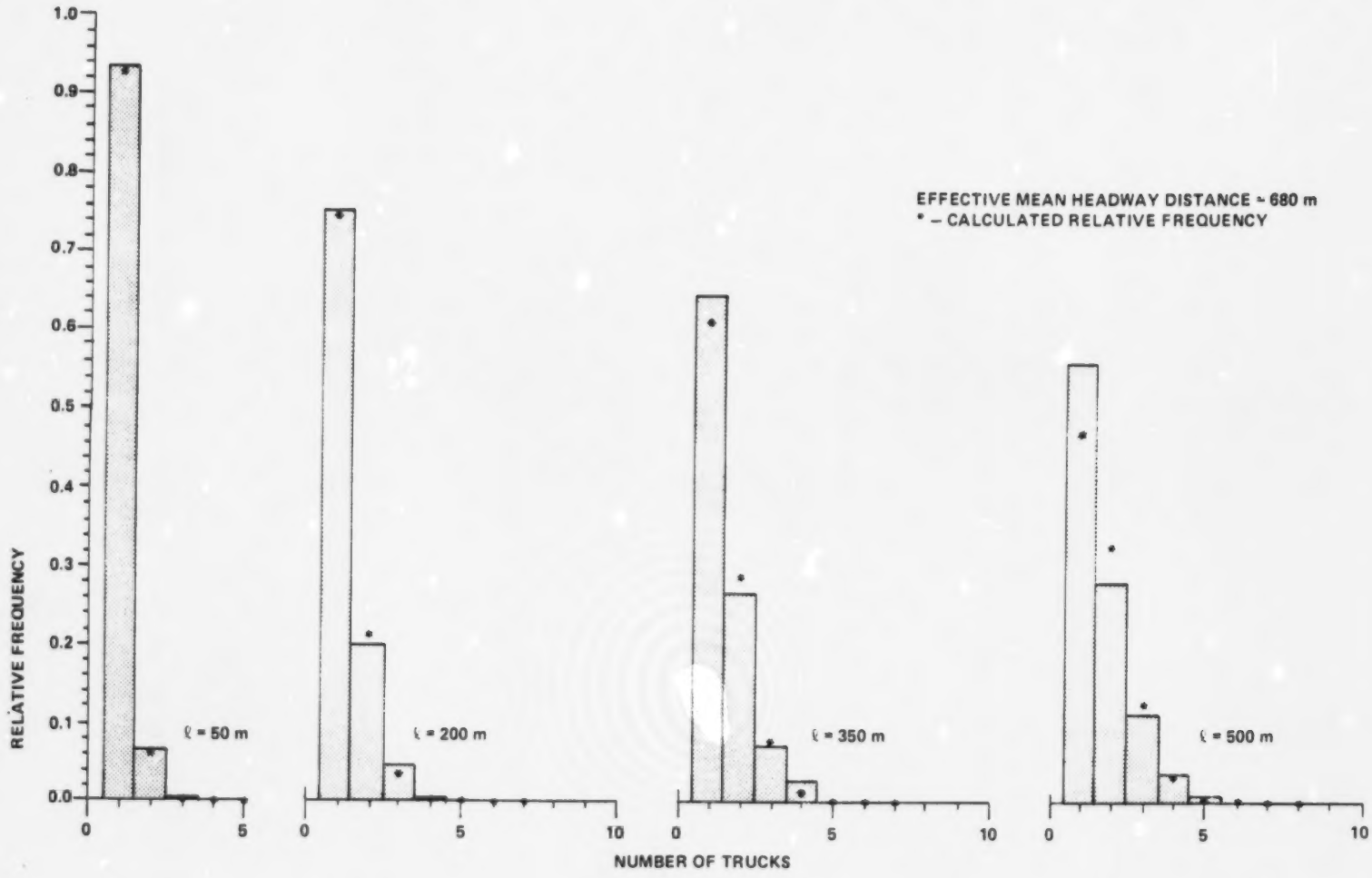

Figure 8(a) I/ Histograms of Multiple Truck Presence on Keele Street, East and Centre Lanes in Moving Traffic

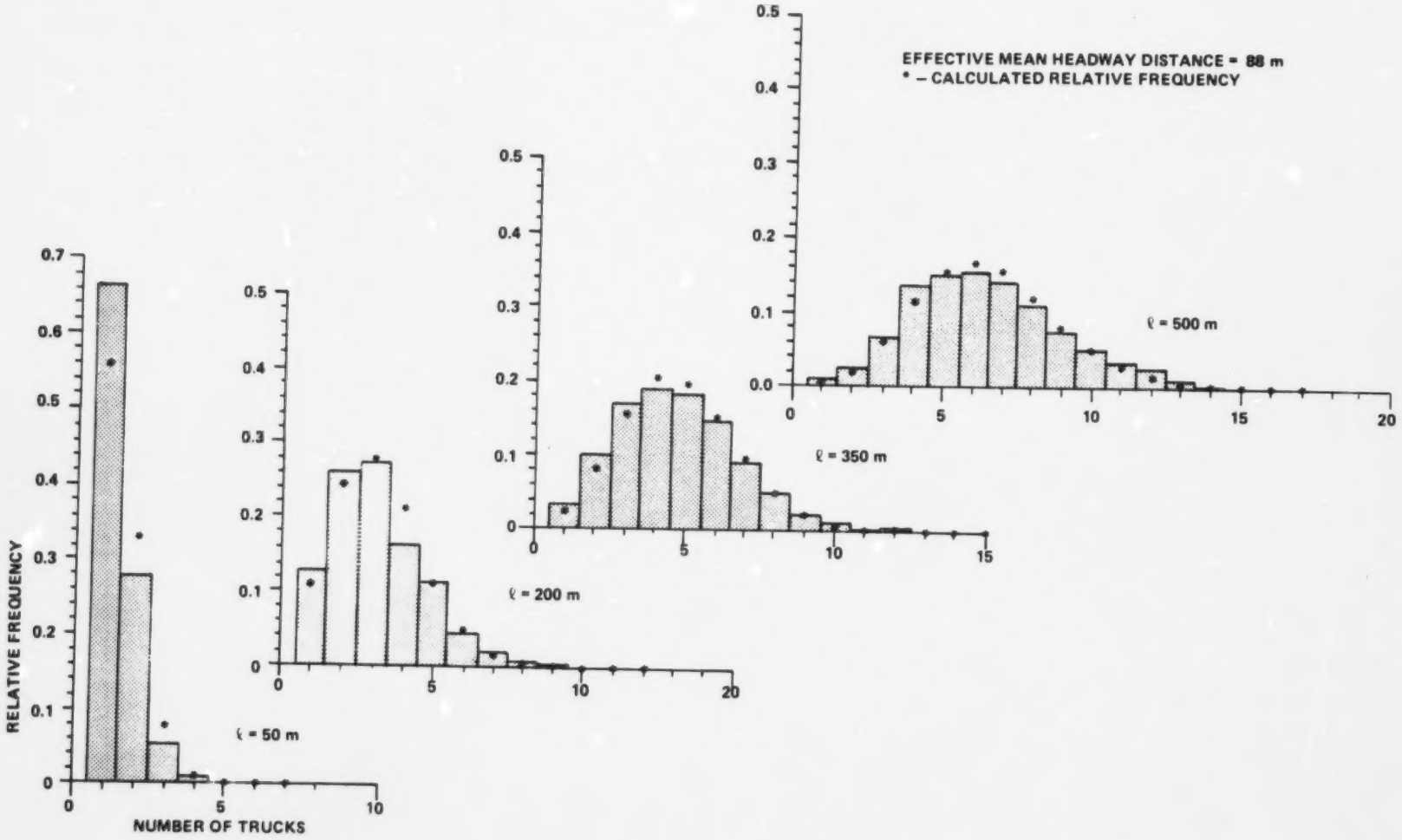
EFFECTIVE MEAN HEADWAY DISTANCE = 88 m
* – CALCULATED RELATIVE FREQUENCY
RELATIVE FREQUENCY
NUMBER OF TRUCKS
ℓ = 50 m
ℓ = 200 m
ℓ = 350 m
ℓ = 500 m

Figure 8(a) II/ Histograms of Multiple Truck Presence on Keele Street, East and Centre Lanes in Simulated Congested Traffic

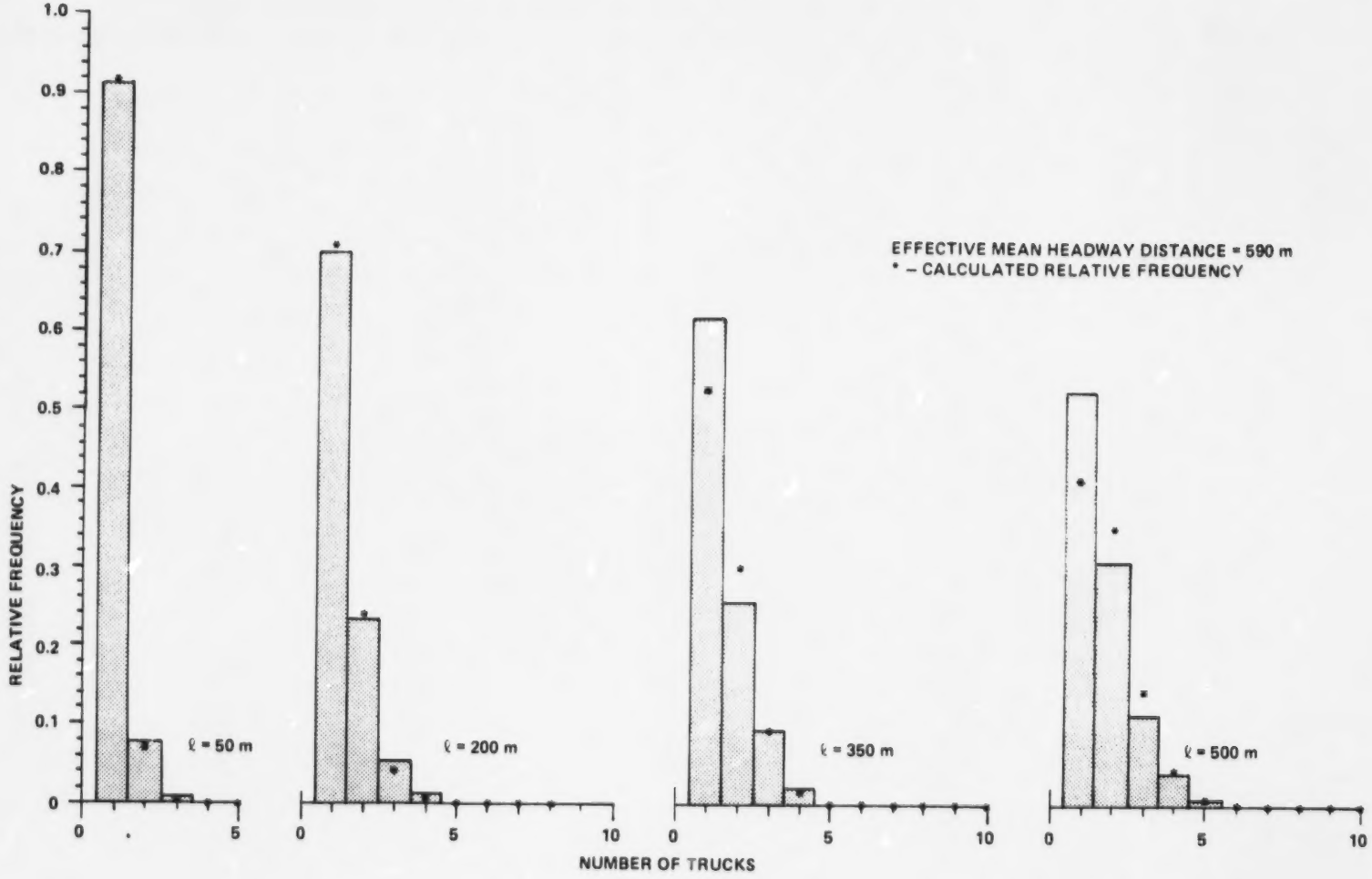
EFFECTIVE MEAN HEADWAY DISTANCE = 590 m
* – CALCULATED RELATIVE FREQUENCY
RELATIVE FREQUENCY
NUMBER OF TRUCKS
ℓ = 50 m
ℓ = 200 m
ℓ = 350 m
ℓ = 500 m

Figure 8(b) I/ Histograms of Multiple Truck Presence on Keele Street, Centre and West Lanes in Moving Traffic

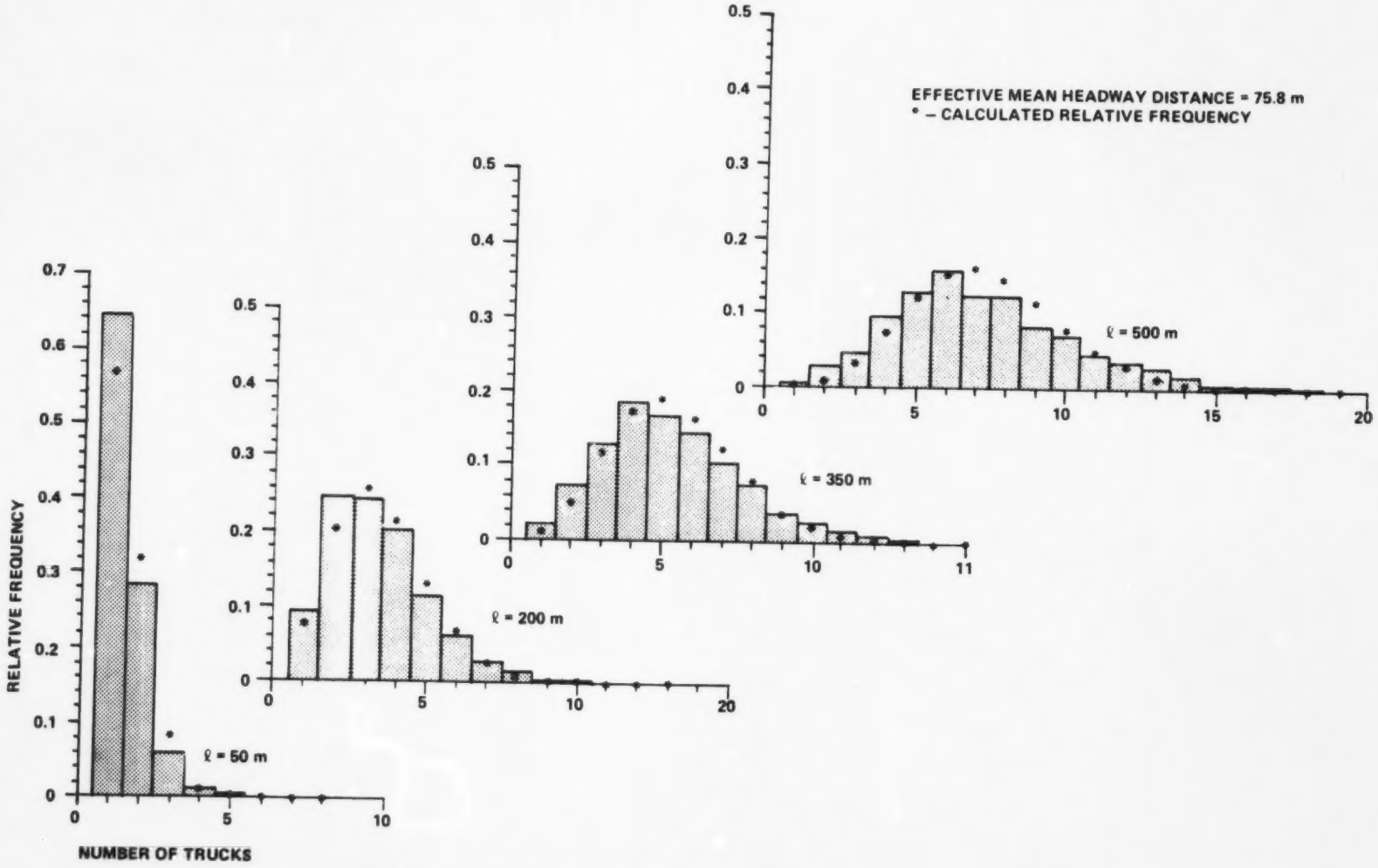
EFFECTIVE MEAN HEADWAY DISTANCE = 75.8 m
* – CALCULATED RELATIVE FREQUENCY
RELATIVE FREQUENCY
NUMBER OF TRUCKS
ℓ = 50 m
ℓ = 200 m
ℓ = 350 m
ℓ = 500 m

Figure 8(b) II/ Histograms of Multiple Truck Presence on Keele Street, Centre and West Lanes in Simulated Congested Traffic

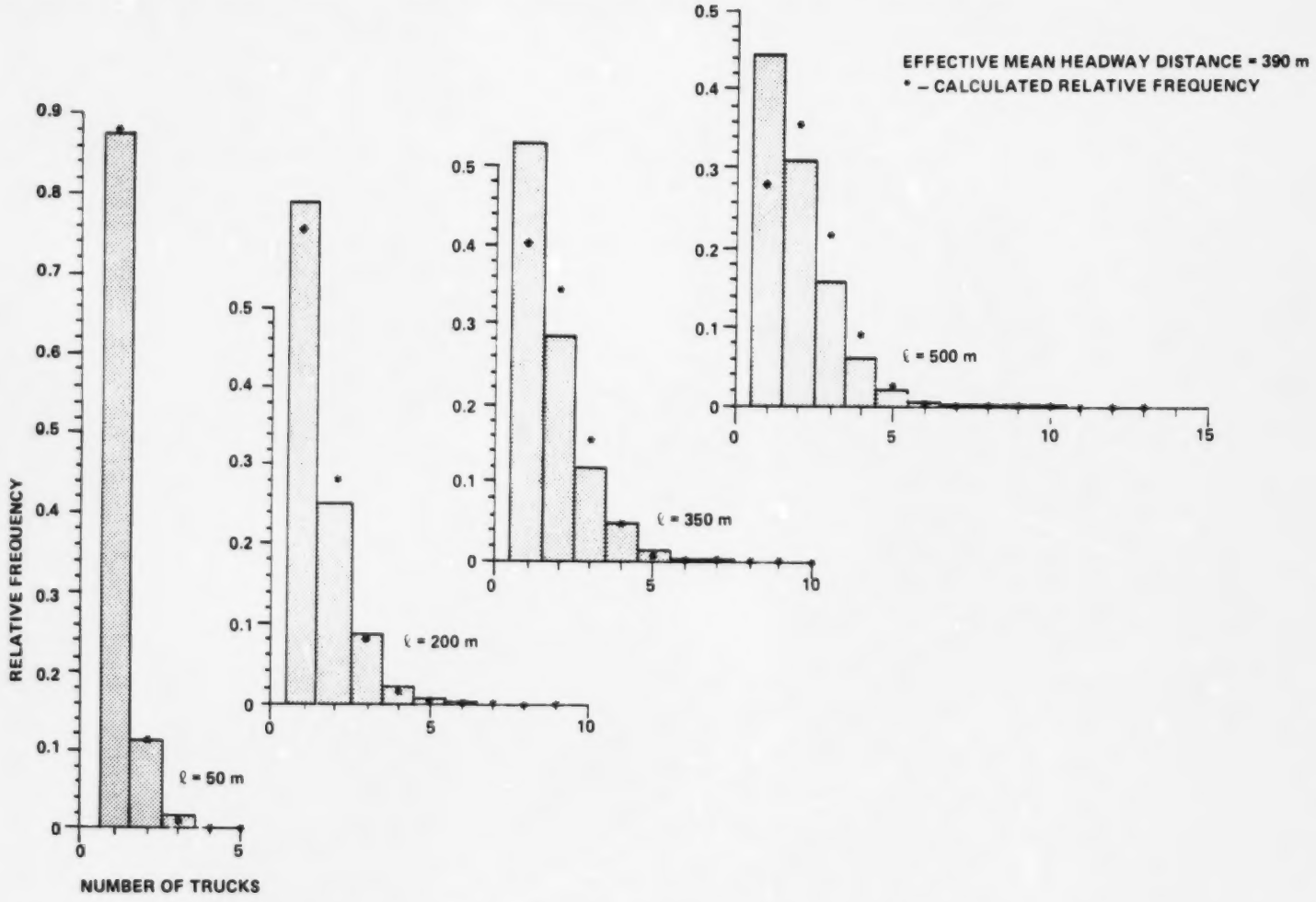
EFFECTIVE MEAN HEADWAY DISTANCE = 390 m
* – CALCULATED RELATIVE FREQUENCY
RELATIVE FREQUENCY
NUMBER OF TRUCKS
ℓ = 50 m
ℓ = 200 m
ℓ = 350 m
ℓ = 500 m

Figure 8(c) I/ Histograms of Multiple Truck Presence on Keele Street, East, Centre and West Lanes in Moving Traffic

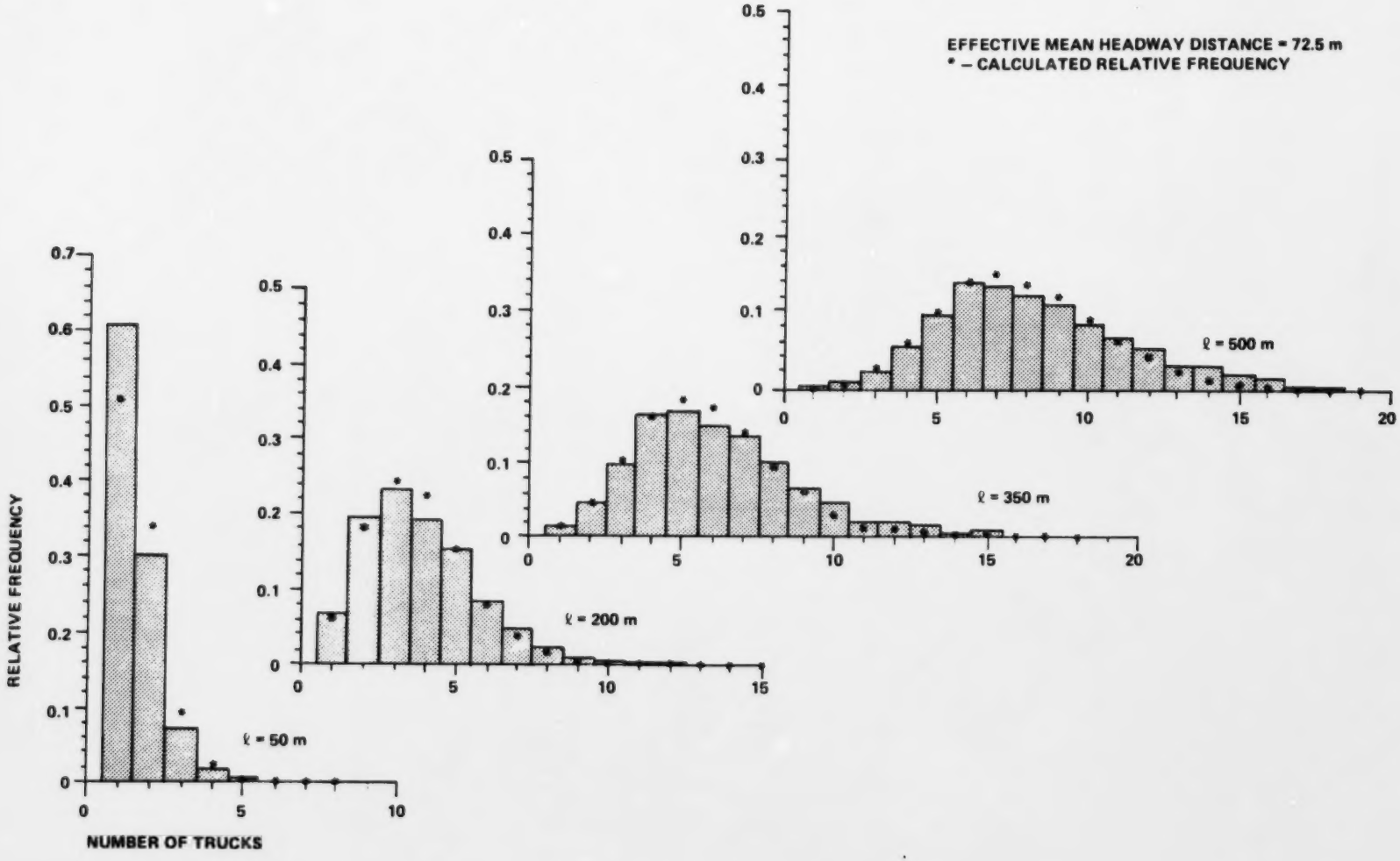
EFFECTIVE MEAN HEADWAY DISTANCE = 72.5 m
* – CALCULATED RELATIVE FREQUENCY
RELATIVE FREQUENCY
NUMBER OF TRUCKS
ℓ = 50 m
ℓ = 200 m
ℓ = 350 m
ℓ = 500 m

Figure 8(c) II/ Histograms of Multiple Truck Presence on Keele Street, East, Centre and West Lanes in Simulated Congested Traffic

Lane	Mean Truck Headway Distance (Calculated Directly)	Effective[1] Mean Truck Headway Distance	Combined[2] Mean Truck Headway Distance	Effective[1] Mean Truck Headway Distance
i) In Moving Traffic				
East	2490*	2532	837	680
Centre	1284	1251		
Centre	1284	1251	695	590
West	1811	1566		
East	2490	2532	545	390
Centre	1284	1251		
West	1811	1566		
ii) In Simulated Congested Traffic				
East		303	82.3	88.0
Centre		113		
Centre		113	70.6	75.8
West		188		
East		303	57.2	72.5
Centre		113		
West		188		

* All values in m.

Notes: [1] Value calculated to cause a best fit of the distribution to the multiple presence data.
[2] Value calculated assuming traffic in adjacent lanes to be independent.

Figure 9/ Mean Truck Headway Distances on Keele Street